Data Hiding Capacity and Embedding Techniques for Printed Text Documents

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Abstract

In previous publications we have demonstrated the use of laser intensity modulation to embed information in halftone and text documents. In those experiments we were able to embed and correctly decode 33 bits in a 12 point page of printed text. In this paper we will present our current work on developing a channel model for a text document. This model will allow us to define capacity bounds for the channel and to better understand the modulation and detection techniques that can be used to reach that capacity. [1]

Introduction

In today's digital world securing different forms of content is important in terms of protecting copyright and verifying authenticity. [1, 2, 3, 4, 5, 6, 7] One example is watermarking of digital audio and images. We believe that a marking scheme analogous to digital watermarking but for documents is very important.[1] Printed material is a direct accessory to many criminal and terrorist acts. Examples include forgery or alteration of documents used for purposes of identity, security, or recording of transactions. In addition, printed material may be used in the course of conducting illicit or terrorist activities. Examples include instruction manuals, team rosters, meeting notes, and correspondence. In both cases, the ability to identify the device or type of device used to print the material in question would provide a valuable aid for law enforcement and intelligence agencies. We also believe that average users need to be able to print secure documents, for example boarding passes and bank transactions.

There currently exist techniques to secure documents such as bank notes using paper watermarks, security fibers, holograms, or special inks.[8, 9] The problem is that the use of these security techniques can be cost prohibitive. Most of these techniques either require special equipment to embed the security features, or are simply too expensive for an average consumer. Additionally, there are a number of applications in which it is desirable to be able to identify the technology, manufacturer, model, or even specific unit that was used to print a given document.

We propose to develop two strategies for printer identification based on examination of a printed document. The first strategy is passive. It involves characterizing the printer by finding intrinsic features in the printed document that are characteristic of that particular printer, model, or manufacturer's products. We refer to this as the *intrinsic signature*. The intrinsic signature requires an understanding and modeling of the printer mechanism, and the development of analysis tools for the detection of the signature in a printed page with arbitrary content.

The second strategy is active. We embed an *extrinsic signature* in a printed page. This signature is generated by modulating the process parameters in the printer mechanism to encode identifying information such as the printer serial number and date of printing. To detect the extrinsic signature we use the tools developed for intrinsic signature detection. We have successfully been able to embed information into a document with electrophotographic (EP) printers by modulating an intrinsic feature known as "banding".[10]

We have previously reported techniques that use the print quality defect known as *banding* in electrophotographic (EP) printers as an intrinsic signature to identify the model and manufacturer of the printer.[11, 12, 13] We showed that different printers have different sets of *banding frequencies* which are dependent upon brand and model. This feature is relatively easy to estimate from documents with large midtone regions. However, it is difficult to estimate the banding frequencies from text. The reason for this is that the banding is present in only the process direction and in printed areas. The text acts as a high energy noise source upon which the low energy banding signal is added.

One solution which we have previously reported in [14, 15, 16] is to find a feature or set of features which can be measured over smaller regions of the document such as individual text characters. If the print quality defects are modeled as a texture in the printed areas of the document then texture features can be used to classify the document. These types of features can be more easily measured over small areas such as inside a text character. A similar technique is also described in [17] for identifying ink jet printers.

Embedding extrinsic features into the document also requires knowledge of the specific print mechanism. During the past few years, many techniques to reduce banding artifacts have been successfully demonstrated by modulating various process parameters such as laser intensity/timing/pulse width (exposure modulation)[18], motor control [19], and laser beam steering[20]. These techniques can also be used to inject "artificial" banding signals that are not intrinsic to the printer. The technological understanding and capability to implement these techniques are not easily obtained meaning it will be difficult for someone to "hack" it.

One issue with embedding extrinsic signatures is that the information should not be detectable by the human observer but needs to be detectable by suitable detection algorithms.[10] This can be accomplished by exploiting the band-pass characteristics of the human visual system with regard to contrast sensitivity.

Previously we have demonstrated this ability to embed an

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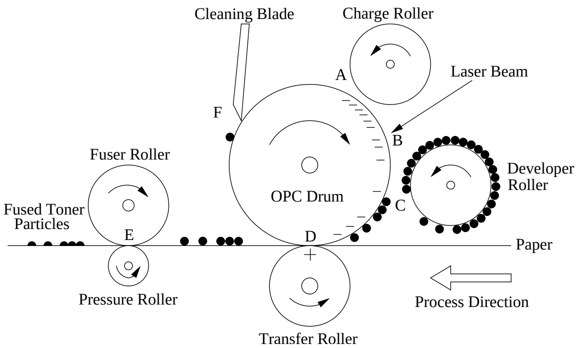

Figure 1. *Diagram of the EP process: (A) charging, (B) exposure, (C) development, (D) transfer, (E) fusing, (F) cleaning*

extrinsic signature in documents which contain halftone images or text.[10, 21] Using a frequency shift keying modulation scheme, we were able to embed 33 bits into a full page of 12 point text, or 2 bits for every three lines.

In the following sections we will present our current work on modeling of the text document as a communication channel. By doing so we can gain further insight into the types modulation techniques and signal types that can be used to increase the embedding capacity.

EP Embedding Techniques

Figure 1 shows a side view of a typical EP printer. The print process has six steps. The first step is to uniformly charge the optical photoconductor (OPC) drum. Next a laser scans the drum and discharges specific locations on the drum. This is the "exposure" step. The discharged locations on the drum attract toner particles which are then attracted to the paper which has an opposite charge. Next the paper with the toner particles on it passes through a fuser and pressure roller which melts and permanently affixes the toner to the paper. Finally a blade or brush cleans any excess toner from the OPC drum.

In EP printing, artifacts are created in the printed output due to electromechanical imperfections in the printer such as fluctuations in the angular velocity of the OPC drum, gear eccentricity, gear backlash, and polygon mirror wobble. In previous work we have shown that these imperfections are directly related to the electromechanical properties of the printer. This property allows the corresponding fluctuations in the developed toner on the printed page to be treated as an intrinsic signature of the printer.

The most visible print quality defect in the EP process is banding, which appears as cyclic light and dark bands most visible in midtone regions of the document. Many banding reduction techniques have been successfully demonstrated. These techniques, three of which are laser intensity/timing/pulse width[18], motor control[19], and laser beam steering[20], actively modulate certain process parameters.

It is desirable to inject signals with high spatial frequency where the human visual system has relative low contrast sensitivity. Among the methods mentioned above, motor control has difficulty controlling the EP process at high spatial frequencies due to inherent electro-mechanical limitations. Laser beam steering requires additional process capability that is not found in typical

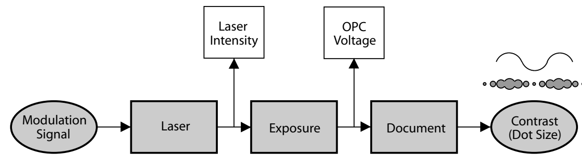

Figure 2. *Process block diagram for embedding extrinsic banding signature using laser intensity modulation*

EP engines. However, modulating various laser parameters to affect exposure, such as laser power, is common practice in typical EP process controls.

As we have shown in[10, 22, 21], these techniques can be used to inject an "artificial" banding signal into the document. In particular, we presented a system shown in Figure 2 using laser intensity modulation which allows per-scan-line changes in laser intensity. The signals used for embedding include a set of sinusoids at various frequencies and amplitudes such that they lie below the human visual sensitivity threshold curve. If the embedded document has any large midtone gray patches, the signal is easily detectable using Fourier analysis techniques. If the document contains text, the signal can be detected through analysis of the estimated edge profiles of the characters.

Channel Model and Experimental Results

A channel model of a printed text document is necessary for understanding the capacity limits and embedding techniques that can be used for embedding extrinsic information into a document. One approach is to model each individual text line as a signaling period during which one channel symbol is sent. At the decoder side, the fact that each individual character contains a version of the same channel symbol can be viewed as a form of multipath receiver diversity.

Given a printer with resolution R_p DPI, ideally the allowable embedding bandwidth would be $R_p/2$ cycles/inch. However, after taking into account the printer MTF this drops significantly. Furthermore, the signaling period length determines the frequency resolution at the decoder. For a font size f_s, the maximum signaling period length is $L_{max} = \frac{f_s}{72} * R_s$ where R_s is the scan resolution. The smallest resolvable frequency separation is then $\frac{R_s}{L_{max}}$. For 12 point text this means $L_{max} = 400$ which gives between 6 and 18 cycle/inch separation for uppercase and lowercase characters respectively for a 2400 DPI scan.

Given these observations a PSK signal set is defined at each of 9 frequencies $f_i = 20, 30, 40, \ldots, 100$ to create the signals

$$x_{i,\theta}(y) = sin\left(\frac{2 * \pi * f_i * y}{R_s} + \theta\right); \quad (1)$$

The purpose of these signals is to estimate the channel gain at various frequencies and determine whether we can easily detect the frequency and phase of the signal using the DFT and a correlation detector.

To determine which frequency was embedded in each line, the following process is performed. First the edge profile $\hat{x}(y)$ is found for the left edge of each character in the line. The power spectral density (PSD) of the profile is obtained using a 240 point DFT as shown in Equation 2. 240 points are used to create 10

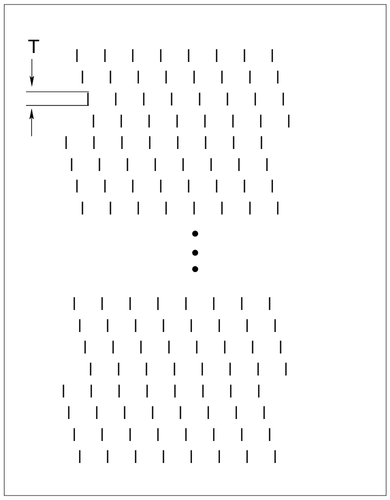

Figure 3. *Test document*

cycle/inch wide bins centered at the frequencies of interest.

$$PSD(f) = \left(\sum_{n=0}^{239} \hat{x}(y) e^{\frac{2*\pi*f*n*y}{240}} \right)^2 \tag{2}$$

The PSDs for each edge profile are averaged together, and the original embedding frequency is chosen as the one with the highest power.

After estimation of the embedding frequency $f_{\hat{i}}$, a correlation detector is used to estimate the phase of the embedded signal. Each edge profile $\hat{x}(y)$ is correlated with $x_{\hat{i},\theta}(y)$ and the theta which gives the greatest correlation is used as the estimate $th\hat{e}ta$.

These signals $x_{i,\theta}(y)$ are embedded in a test document as shown in Figure 3 consisting of 12 point hight vertical lines. The page is printed on an HP Color LaserJet 5M, which is a 600 DPI printer. The printed page is then scanned using an Epson Perfection 4490 flatbed scanner at 2400 dpi in 16 bit grayscale mode with no exposure correction.

4-PSK signal sets are used at each of the frequencies $f_i = 20, 30, 40, \ldots, 100$. Line n in the test page is embedded with signal

$$x_{floor\frac{i-1}{4}+1,\frac{\pi}{2}4floori/4} \tag{3}$$

Thus every four lines will have the same frequency, with each successive line having a $\pi/2$greater phase offset.

Three test pages were printed with modulation amplitude of 0.1, 0.2, and 0.3 respectively. The PSDs for each frequency are estimated and plotted for each page. Figures 4 and 5 show these results for modulation amplitudes of 0.1 and 0.2. These plots show that the channel gain decreases with frequency. Low frequency signals can be embedded at lower amplitudes while high frequency signals need a larger amplitude to rise above the channel noise. The choice of embedding amplitude such that it does not increase edge raggedness can be guided by the work in [22].

Estimating the phase of the embedded signal is slightly more difficult. Ideally, every scanline will be parallel to one another and perfectly straight. In this case, a linear estimate of the phase drift due to a slight skew in the scanned image can be made on the first line and used for each subsequent line. Also the top most

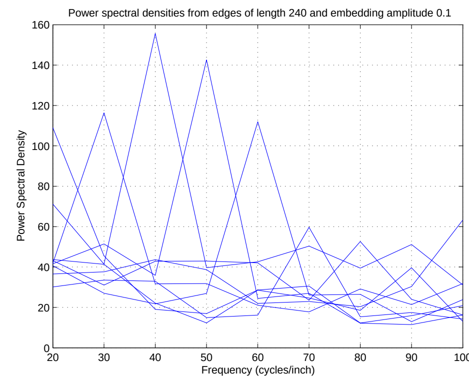

Figure 4. *PSDs for each frequency embedded with amplitude* 0.1

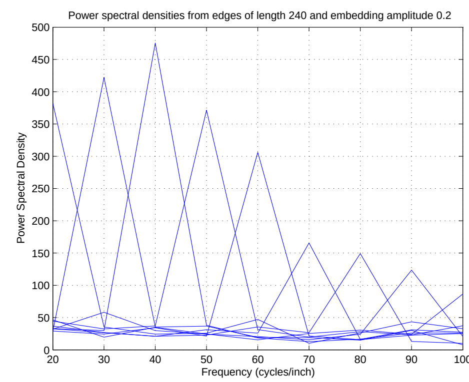

Figure 5. *PSDs for each frequency embedded with amplitude* 0.2

scanline for each text line can be used as a phase reference for each character in that line.

However, in actuality the scanlines on the printed page are not perfectly straight and are not perfectly parallel to one another across the entire page. The phase drift across one text line can vary by up to 1 full cycle from a linear estimate. Shown in Figure 6 is a plot of character offsets for individual textlines in one text document. The rightmost character in each textline was used as the reference. For this particular page, text lines located further down the page have a larger slope for the character offset. Improved phase estimation based on individual character features, such as character baseline, may allow full utilization of phase information in this channel.

Conclusion and Future Work

The experimental results appear very promising for further development of our proposed channel model, modulation, and detection techniques. Further work needs to be investigated on phase estimation and signal signal design. With the modulation technique described in the previous section, approximately 3 bits can be embedded in every line of text without using any phase information. Assuming the phase estimation problem can be overcome, this increases to approximately 5 bits in every line of text. For a 12 point text document this is approximately 250 bits in the entire page.

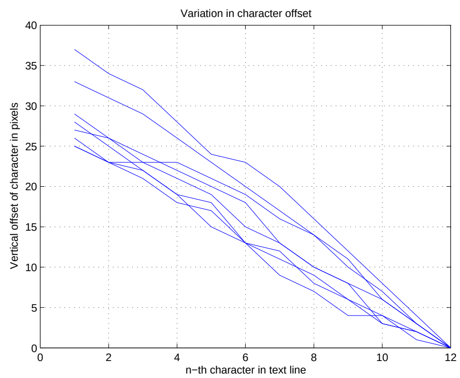

Figure 6. *Character offset for individual text lines in a document*

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