Application Of High Capacity Data Hiding In Halftone Images

Orhan Bulan**, *Gaurav Sharma**, *Vishal Monga*+; *ECE Dept. Univ. of Rochester Rochester, NY 14627-0126 ; +Xerox Research Center Webster Webster, NY 14580

Abstract

We consider applications of our recently proposed method for hiding digital data in halftone images via dot orientation modulation. As compared to prior halftone image watermarking techniques, the method allows for automated extraction of the data and relatively high capacity. These characteristics enable several new applications that we highlight in this paper. By quantifying the effective error free operational rates obtained with suitable error correction codes in our experimental evaluations, we identify the rate constraints on feasible applications. In particular, our estimates indicate that the method can be utilized for a) embedding thumbnails of images for validation and authentication, b) embedding speech in printed images in order to improve accessibility for the visually impaired, and c) embedding text for carrying meta-data pertaining to the image in the printed image itself (e.g. biography in portrait). We demonstrate a working prototype illustrating the applications.

Introduction

Methods that allow data embedding in hardcopy prints can be useful for a variety applications [1–5]. Some of these applications can be listed as: 1) fingerprinting (identifying where a hardcopy document is originated), 2) integrity verification (ensuring that the original document is distinguishable from copies), 3) copyright enforcement (identifying owner from the hardcopy document), 4) meta-data and auxiliary data embedding.

Data embedding in hardcopy prints constitutes a challenging problem due to various distortions introduced by the print-scan process (i.e rotation, local geometric distortions, noise on the input graylevel). This kind of channel adversely affects the detection accuracy and limits maximum achievable embedding rate. The majority of existing hardcopy data embedding methods therefore, can only allow low capacity applications such as simple meta-data tagging and authentication type applications [6–8].

High data embedding capacity, on the other hand, is desired in a variety of applications e.g. auxiliary data embedding. We have recently proposed a high capacity embedding method for halftone images [9–11]. Our method enables several new applications for hardcopy data embedding that require high capacity. In this paper we consider three of these applications: 1) thumbnail embedding for authentication, 2) speech embedding for accessibility, and 3) text meta-data embedding. We demonstrate an implementation realizing the first of these applications and estimate the operational parameters for the other two cases.

System Overview

The application scenarios that we consider rely on the embedding of auxiliary information into a printed halftone image in order to provide additional operational features. In our framework, we perform the embedding of the auxiliary information during the halftoning process. Once the halftone image is printed, the resulting printed image can be utilized in much the same way as any other printed image. When the printed image is scanned, however, the embedded auxiliary data may be recovered and can provide additional operational features. For example, if the auxiliary data is an encrypted thumbnail of the original contone image, the recovered data serves the purpose of "authenticating the print". On the other hand if the embedded information contains an audio caption describing the image, it can enhance the interaction of a visually impaired individual with the print, when used with a device capable of playing back the audio. In a similar fashion, embedded text can provide additional functionality by providing meta-data relating to the image or additional commentary on its content.

Since the print-scan cycle in this process is prone to various imaging distortions, in order for these applications to work, some form of error control coding is necessary prior to embedding of the auxiliary data. Accordingly, the system block diagram takes the form shown in Fig. 1. The contone image to be printed is denoted here by $I(x,y)$ and $\mathbf{m}$ denotes the vector of auxiliary data that we wish to communicate, where x,y denote the spatial coordinates. We first introduce redundancy in the auxiliary data $\mathbf{m}$ by error control coding to obtain the encoded data vector $\mathbf{c}$. As the contone image $I(x,y)$ is halftoned to obtain a binary representation $I^h(x,y)$ suitable for printing this coded data $\mathbf{c}$ is embedded in the halftone image i.e. the data embedding and halftoning is performed jointly.

The halftone image $I^h(x,y)$ is printed and the resulting print can be utilized for any purpose that other prints (without embedding) may be utilized. Upon scanning the print the scanned image $I^s(x,y)$ is obtained. The embedded auxiliary data $\mathbf{m}$ is recovered from $I^s(x,y)$ by extracting suitable detection statistics and performing error control decoding.

Data Hiding Via Halftone Orientation Modulation

We recently proposed a data hiding scheme in clustered dot-halftones using orientation modulation in halftoning process [9]. Specifically, our method allows us to generate elliptically shaped halftone dots oriented along vertical and horizontal directions and embed information in the choice of a particular orientation. Figure 2 shows a zoomed version of a constant graylevel image where the dot orientation is modulated along vertical and horizontal directions. By incorporating the data embedding step within the halftoning process, method ensures that the visual quality of the printed halftones is maintained, even at the cost of robustness/detectability of the embedded data (see [11] for details).

At the receiver, we first compensate for geometric distortions that print-scan process introduces. Following local and global synchronization, we detect the modulated orientation based on

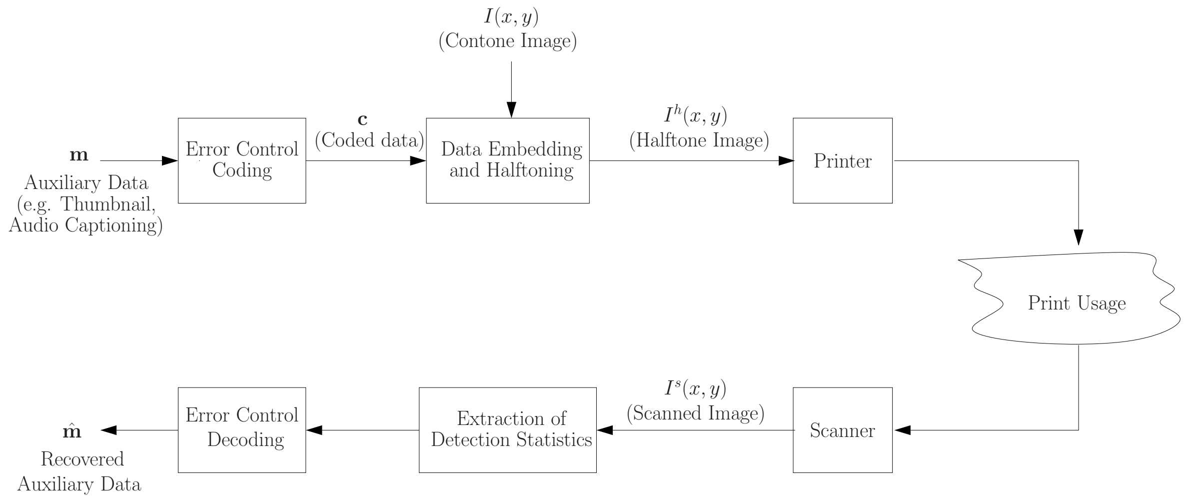
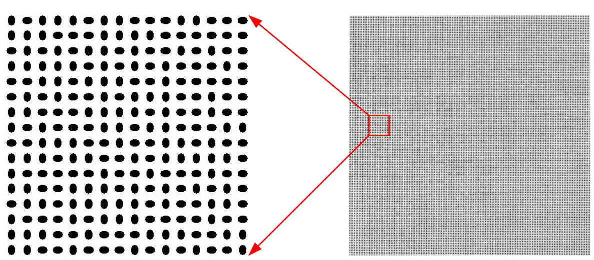


Figure 1. *System block diagram for hardcopy data embedding applications*



(a) Dot orientation along vertical and horizontal directions

(b) Graylevel halftone image

Figure 2. *Orientation based data embedding*

two orthogonal statistically motivated moments computed within each halftone cell from the scan $I^s(x,y)$ of the printed image. The moment along the Y-axis within a halftone cell[1] C is calculated as:

$$\sigma_y = \frac{1}{A} \sum_{x,y \in C} I^s(x,y)(y-\bar{y})^2 \tag{1}$$

where $A = \sum_{x,y \in C} I^s(x,y)$ and $\bar{y} = \frac{1}{A} \sum_{x,y \in C} I^s(x,y)y$ represents the ordinate of the center of mass of the halftone dot. The moment σ_x along horizontal direction can also be computed in a similar way.

Orientation Modulation Channel Model and Error Recovery

Channel Model

The print-scan channel exhibits a strong dependence on the cover image especially on the local cover image graylevel. For instance, it is trivially apparent that no orientation modulation is possible for area coverages of 0% and 100% since there are no "halftone dots" in these extreme cases. Similarly, the 50% area coverage case poses a challenge. In our recent work [11], we exploit this dependence and develop an image adaptive decoding algorithm that is incorporated within the error correction coding. In order to incorporate channel dependence on cover image content in our error recovery scheme, we propose a statistical modeling of the channel in the form of a conditional density function $f(\sigma_x, \sigma_y \mid \Theta_i, g)$ where the received moments are conditioned on the local image graylevel g and, horizontal and vertical orientations Θ_i, $i = 1,2$. Assuming conditional independence of individual received moments[2] we express the joint conditional density function as the multiplication of two individual conditional densities $f(\sigma_x \mid \Theta_i, g)$, $f(\sigma_y \mid \Theta_i, g)$. We characterize the individual conditional density functions from experimentally determined histograms from printed test images.

Channel Coding and Decoding

Based on the probabilistic modeling of the print-scan channel, we utilize near capacity achieving Repeat Accumulate (RA) codes [12,13] for error and erasure recovery. In RA codes, the encoder is composed of three stages. An information block of length M is repeated r times, scrambled by an interleaver of size rM, and then encoded by a rate 1 accumulator. The rate of the RA code is $1/r$ and is readily changed simply by changing the repetition factor r.

The image adaptive decoding process [11] for the RA codes is illustrated in Fig.3. At the receiver, we first estimate the local graylevel g and extract the moments. Then a soft decision measure is computed based on the statistical channel model, extracted moments and estimated local graylevel. This measure is passed on to the RA decoder which returns on estimate of the embedded auxiliary data $\hat{\mathbf{m}}$.

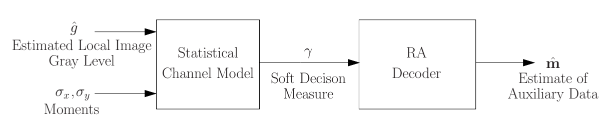


Figure 3. *Soft error control decoding for recovery of embedded data.*

[1] Our description readily assumes less than 50% area coverage. The case for greater than 50% area coverage is readily handled by inverting the image.

[2] We validated this assumption experimentally in prior work [9].

Applications

Data hiding in printed images via halftone dot orientation modulation allows automated data extraction and offers high capacity for data embedding. This enables various new hardcopy data hiding applications. Here, we highlight applications of image, speech and text embedding in printed images.

Image Embedding for Authentication

The authenticity of digital images can be readily verified by utilizing digital signatures [14, 15] that may also be incorporated within the image data itself as authentication watermarks [16, 17]. For printed images, however, establishing authenticity is significantly more challenging because of the inherent distortions within the printing process that render fragile digital signatures non-functional. The relatively high capacity of the halftone orientation modulation method presents an interesting alternative for printed image authentication.

The method operates by embedding within the printed image, a digital thumbnail version of the contone image where the digital thumbnail is either encrypted or carries within it a self-authenticating cryptographic digital signature [14, 15]. A receipent of the hardcopy image can then authenticate the printed image by extracting and authenticating the thumbnail image by conventional methods for digital authentication, and then establishing the authenticity of the printed image by visual/automated comparison against the thumbnail. In this context, the thumbnail serves as a robust hash for the printed image, albeit of a rather large size.

A block diagram for this scheme for hardcopy image authentication based on thumbnail embedding is shown in Fig. 4. We first scale and JPEG compress the contone image and generate an encrypted/signed digital thumbnail that fits within the available capacity. The resulting data is then error control coded and embedded in the halftone rendition of the contone image via orientation modulation method. Note that the size of the data that can be embedded depends on the content of the contone image. The scaling and compression can, however, be adjusted in order to permit the embedding. The following table lists the combination of JPEG quality factor and thumbnail size that can be embedded within a typical 8×8 inch square printed image.

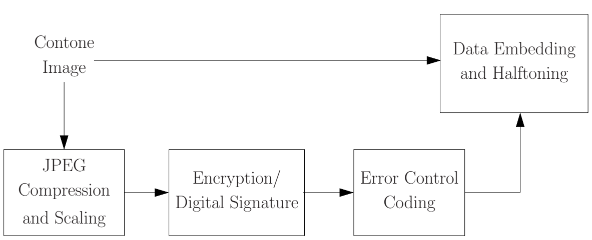


Figure 4. *Thumbnail embedding for hardcopy image authentication.*

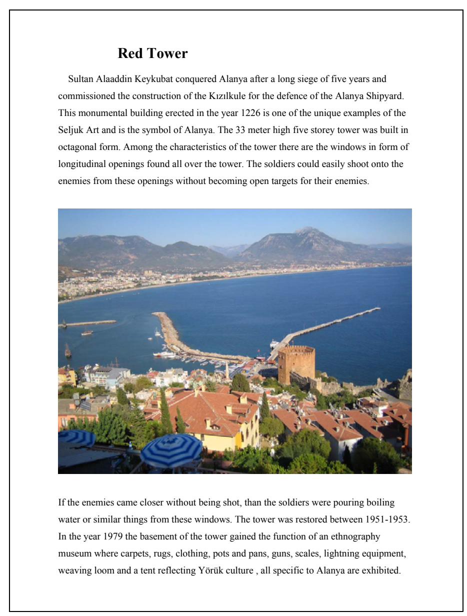
QF	Thumbnail size
100	110×110
80	220×220
60	270×270
40	320×320

Thumbnail size that can be embedded in a typical 8×8 inch square printed image with various JPEG quality factors.

Speech Embedding for Accessibility

One of the main challenges for visually impaired individuals is that although they can read a written text by utilising text to speech devices, images remain unrecognized for those devices. Figure 5 illustrates such a case where an image is placed in the middle of a text document. In order for visually impaired person to visualize the content of the image one way would to write a text in the caption that explains the content of the image. But this kind of a text in the caption would be visually distracting for non-impaired individuals. This shortcoming can be overcome by embedding speech in the printed image via halftone dot orientation modulation. The embedded speech can provide information on the image to the visually impaired while remaining completely unobtrusive.

Figure 6 illustrates the block diagram for speech embedding in hardcopy images. Speech is first compressed by audio-multi rate (AMR) which is a widely used speech data compression scheme. The compressed speech is then coded and embedded in the cover image jointly with halftoning. In the following Table, we list the durations of speech that can be embedded in a typical 8×8 inch square printed image. The speech duration that can be embedded varies from 7.9 sec. to 20.2 sec. for a various AMR modes.



Red Tower

Sultan Alaaddin Keykubat conquered Alanya after a long siege of five years and commissioned the construction of the Kızılkule for the defence of the Alanya Shipyard. This monumental building erected in the year 1226 is one of the unique examples of the Seljuk Art and is the symbol of Alanya. The 33 meter high five storey tower was built in octagonal form. Among the characteristics of the tower there are the windows in form of longitudinal openings found all over the tower. The soldiers could easily shoot onto the enemies from these openings without becoming open targets for their enemies.

If the enemies came closer without being shot, than the soldiers were pouring boiling water or similar things from these windows. The tower was restored between 1951-1953. In the year 1979 the basement of the tower gained the function of an ethnography museum where carpets, rugs, clothing, pots and pans, guns, scales, lightning equipment, weaving loom and a tent reflecting Yörük culture , all specific to Alanya are exhibited.

Figure 5. *Image in a text document.*

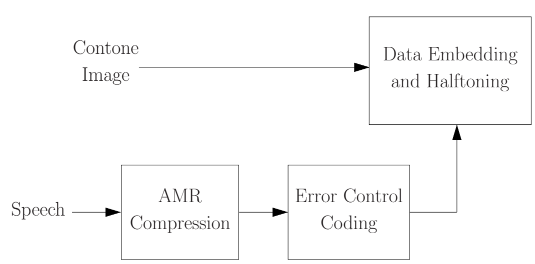


Figure 6. *Speech embedding for accessibility.*

Mode	Bit Rate (kbit/sec)	Speech Length (sec)
AMR(12.20)	12.20	7.9
AMR(10.70)	10.70	8.9
AMR(7.95)	7.95	12.0
AMR(7.40)	7.40	13.0
AMR(6.70)	6.70	14.3
AMR(5.90)	5.90	16.3
AMR(5.15)	5.15	18.6
AMR(4.75)	4.75	20.2

Speech length that can be embedded in a typical 8×8 inch square printed image with various AMR modes.

Text Embedding

We also consider embedding text in printed images for carrying meta-data pertaining to the image. An illustrative example is that embedding biography in a portrait for authentication and validation purposes.

Our data embedding technique halftone-dot orientation modulation allows to embed 2000 words that contains 12000 characters in a typical 8×8 inch square printed image. By using well-known text compression technique zip, this capacity can be significantly increased by a factor of upto 125, thereby allowing for a substantial amount of text data to be embedded.

Results

We demonstrate a working prototype for our proposed applications selecting thumbnail embedding for illustration. The halftone images were printed on Xerographic printer that had an addressability of 2400 dots per inch (dpi). The self-embedding based authentication method shown in Fig. 4 was tested over a number of contone images printed on this printer, where each image was rendered so as to cover an 8×8 inch square area on the printed page. The resulting print was then scanned on a desktop scanner with a 1200 dpi resolution and the embedded data was recovered from the scan using the recovery and error control decoding outlined earlier.

For illustrating our results we utilize two contone images: a) a 1600×1600 pixel “Chapel” image and b) a 1672×1672 pixel “Ship” image. These images are shown in Figs. 7(a) and 7(d).

First, we determine the maximum error free embedding rate[3] for both the chapel and ship images by printing data embedded images with embedded data encoded at various RA code rates $1/n$, $n = 2,3,4,5,6..,10$ and determining the highest code rate at which the data can be recovered. We then compute a signed digital thumbnail of the contone image that fits within this error free operational rate. Specifically, for our examples we used a thumbnail generated with a JPEG quality factor (QF) 80 and scaled to a size that would allow it to fit after encoding at the operational rate previously estimated. These sizes were 220×220 for the chapel image and 320×320 for the ship image and the corresponding thumbnails are shown in Fig. 7 (a) and (d). The retrieved thumbnail images at the receiver (recovered without error, after error correction decoding) are shown in Fig.7 (c) and (f). Note that the thumbnails clearly represent the content of the contone image validating the operation of the proposed authentication method.

[3] Note that the embedder can do the same in a practical application or use a conservative rate based on the ensemble of images that it operates on.

Conclusion

We present several hardcopy applications that are made feasible by our previously proposed scheme for halftone data embedding via dot orientation modulation. We note that the high capacity aspect in particular is a key to enabling these applications that are beyond the capabilities of alternative low capacity methods. We presented three applications corresponding to image, speech, and text embedding and demonstrate one particular application that provides a means for reliably authenticating a printed image via the embedding of a self-authenticating digital thumbnail. The data hiding capacity of the method utilized for embedding is dependent on the cover image content. However, for a wide range of natural images the method offers high enough capacity to enable these applications.

Author Biography

Orhan Bulan received the B.Sc. degree in electrical and electronic engineering from Bilkent University, Ankara, Turkey, in 2006 and the M.Sc. degree in electrical and computer engineering from the University of Rochester, Rochester, NY, in 2007. Currently, he is a Research Assistant with the Electrical and Computer Engineering Department, University of Rochester. His research interests include multimedia security, digital watermarking, image processing, and hardcopy data hiding.

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(a) 1600×1600 Chapel image. (b) 220×220 thumbnail of Chapel image. (c) recovered thumbnail of chapel image.

(d) 1672×1672 ship image. (e) 320×320 thumbnail of ship image. (f) recovered thumbnail of ship image.

Figure 7. *Thumbnail embedding in printed images.*

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