GRAPHICAL INDICIA

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ABSTRACT

We present an authenticable graphical barcode symbology, and describe a system for its reliable encoding and decoding. The graphical barcode is generated by modulating halftone patterns according to the message to be embedded in the barcode during the rendering of a base image. The generated barcode has the appearance of the base image, and when it is printed and scanned back in, the message can be retrieved. A graphical indicium is a graphical barcode embedded with a digitally signed message such that the integrity and authenticity of the message can be verified.

1. INTRODUCTION

Barcodes are information-carrying patterns designed for easy and reliable automatic retrieval. The most common barcodes are known as one-dimensional barcodes. These patterns vary in a single dimension (e.g. horizontal), and are redundant in the other (vertical) dimension. In order to convey more information on the same surface area, the redundancy in the vertical dimension has to be abandoned to create more intricate patterns, known as two-dimensional barcodes. An overview of barcodes can be found in [1] while a good coverage of two-dimensional barcode symbologies can be found in [2]. Data Glyph, a two-dimensional symbology (usually not classified as such), is described in [3].

One-dimensional barcodes are employed in low information content applications such as product index registries (e.g. automatic price tagging and inventory management), or serial number registries (e.g. test-tube tagging in automated medical tests). Two-dimensional barcodes are used in applications that require more information to be embedded, including electronic postal indicia, mail addresses (for automated mail reading and distribution systems), or embedding the compressed content of a printed page (e.g., to avoid the need for optical character recognition).

The main drawback of traditional two-dimensional barcodes is that their visual appearance precludes them from being used prevasively. In this paper we propose a new, visually significant, two-dimensional barcode symbology [4], which extends the usability and seamlesness of data carrying patterns. Visual significance is achieved for some compromise in data capacity.

A graphical indicium is an authenticable graphical barcode. The embedded information includes a digital signature that can be used to verify the integrity and the authenticity of the indicium. There are a wide variety of potential applications for graphical indicia. Any e-commerce transaction that requires payment evidence such as concert tickets and electronic stamps, for instance, can leverage this technology. For example, a concert ticket may include the performer's portrait on the ticket as a graphical indicium; an electronic stamp may include acronyms, company logos, or even personalized graphical icons. Graphical indicia could also be used as verifiable Photo ID's.

Graphical barcodes may also be included in a printed document as icons embedding information about the document, such as a link to its digital source or copyright information. Other different approaches to graphical information embedding include data glyphs applied in an icon as a link to the digital source with a pictorial appearance of the thumbnail image of the document [5], the concealogram, which conceals an image in a different halftone image [6], and a data glyph based graphical interface [7].

To enable this, we propose a two-dimensional graphical barcode symbology, namely, a binary dot pattern incorporating fiducial marks, which has a graphical content. Thus, in contrast to traditional symbologies, the proposed symbology uses patterns that have meaning as graphical entities. For example:
- Logos, such as a company, application, or action logo.
- Graphics, including frames, button, or backgrounds.
- Acronyms, for instance, a text box reading "This box contains important data!" containing, naturally, the important data itself (see Figure 1(c)).
- Images.

Figure 1 shows scanned examples of symbologies.

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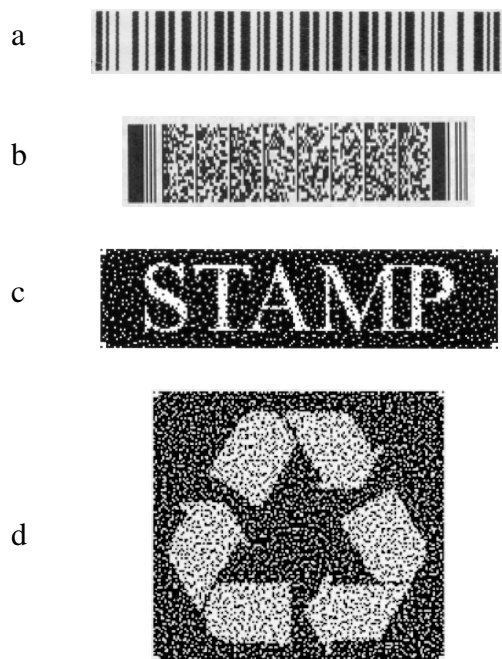3 Chit Wei is currently with RealNetworks, Inc.

Figure 1: Scanned examples of barcode symbologies: (a) one-dimensional barcode, (b) PDF417 two-dimensional barcode, (c) graphical barcode: acronym, (d) graphical barcode: logo.

In this paper we present a system for embedding and decoding these barcodes. The system enables automated identification, and accurate registration of the barcode, which might be read-in in arbitrary orientations. It employs error-correcting codes for reliable retrieval of the embedded information. The decoding processes makes the barcode robust to common office document degradations like copying, folds, stains, marks, and staples. The barcode can be printed and read by standard office imaging equipment like printers, scanners, copiers, and multi-functional equipment.

In contrast to image watermarking methods, the proposed symbology is not imperceptible. In return the data capacity is much higher, and the error rate much lower than what can be achieved in image watermarking. Furthermore, since barcodes are already printed, image deformations and digital attacks are a non issue in our case.

2. GRAPHICAL BARCODES

The proposed graphical barcode system is composed of two sub-systems. The barcode-generating sub-system processes a message and a *base image* (containing, for example, a logo, or any other graphical object), and renders the image as a specific pattern, called the *graphical barcode*, on a hardcopy. Alternatively, it produces a digital representation of the graphical barcode,

which may be incorporated in a document and subsequently printed. The graphical barcode appears similar to the base image. However, embedded within it is a retrievable version of the message. If the hardcopy bearing the barcode pattern is scanned and processed by the barcode-reading sub-system, the original message will be decoded. The two sub-systems and the expected hardcopy -handling path are detailed in Figure 2.
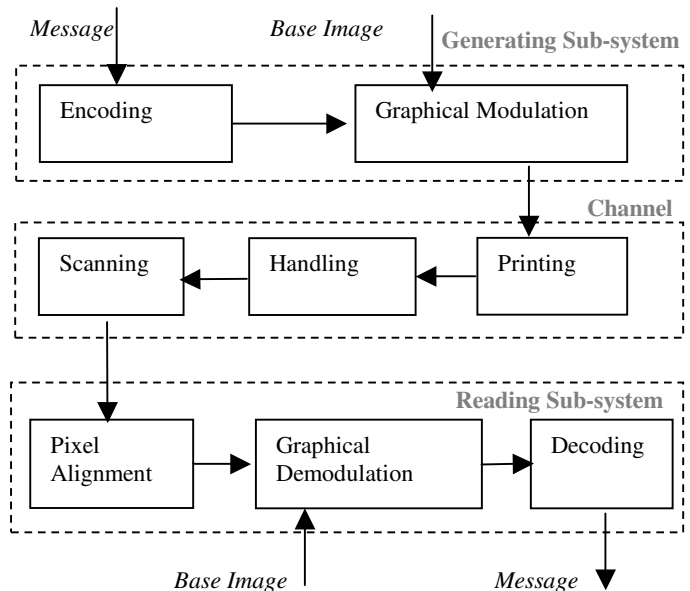

Figure 2: A high-level block diagram of the proposed graphical barcode system.

2.1. Barcode-Generating Sub-System

The graphical barcode is a binary image (black and white dot pattern) produced by the barcode-generating sub-system as follows:

1. The message may first be compressed if necessary into a more compact representation by applying any source compression algorithm.
2. Optionally the input message may be digitally signed using a public key based digital signature algorithm such as RSA [8]. The original message and its digital signature are concatenated to form the digitally signed message.
3. The message is coded using an error-correcting code. The error-correcting code provides resilience to the degradations introduced in the channel. At the end of this encoding stage, the message is turned into a binary bit stream.
4. The base image is partitioned to a rectangular array of *blocks* (for simplicity we assume that the dimensions of the base image are multiples of the block size).
5. Some blocks are reserved for fiducial marks.

6. The remaining blocks are ordered in a sequence. Each block in that sequence encodes a sequence of the message bits. The graphical modulation maps each block to a *binary image block*, using one of a predefined set of distinct halftone patterns. The choice of the halftone pattern is arbitrated by the corresponding sequence in the message bit stream. For illustration only, Figure 3 shows a 2x2 pixel block, 2-bit encoding scheme, a simplistic graphic modulation scheme that maps each block according to whether it is dark or light, and the corresponding bit sequence. For example, if the average intensity of the current block is below 50% and the next input string sequence is 00, then a binary 2x2 image block will be produced where only the upper left pixel is marked.

7. The graphical barcode is composed of the fiducial marks and the binary image blocks placed at their corresponding locations.

8.

Message Block Bits Color	00	01	10	11
Light	◨	◨	◨	◨
Dark	◼	◼	◼	◼

Figure 3: A simplistic graphical modulation scheme.

2.2. Barcode-Reading Sub-System

The image acquired by the scanner and introduced to the barcode-reading sub-system is a degraded version of the barcode image. The degradations are attributed to the channel, namely, the printing and scanning processes, and potential office type degradations like copying, stains, folds, staples, and marks. The scanned image is processed as follows:

1. Initially the barcode image has to be identified within the scanned image (which may contain a full page). It is then cropped, rotated (only in multiples of 90 degrees) and scaled if necessary.

2. The fiducial marks are detected. The configuration of these fiducial marks indicates the type of global deformation introduced by the channel (usually translation, rotation, and skew). The detected global transformation is subsequently corrected to provide for an aligned image.

3. The aligned image is processed to correct for some degradations due to the printing and scanning channel.

4. It is next partitioned to a rectangular array of sub-images, each corresponding to a single binary image block.

5. Each sub-image is compared against the set of possible binary image block patterns (e.g., 2x2 patterns shown in Figure 3). The binary code of the best match represents the sub-image in the output binary sequence. At the end of this demodulation stage, the output is a binary bit stream.

6. The (possibly erroneous) output bit stream is decoded with the original error-correcting code algorithm, thereby eliminating the effect of possible errors due to the degradations introduced by the channel.

7. If the message is digitally signed, then the message and its digital signature are recovered. The digital signature of the retrieved message is decrypted using the sender's public key to reveal the original message digest. This is compared against a new message digest generated from the retrieved message. If the message digests are equal, the authenticity and integrity of the message is verified.

8. If needed the retrieved message is decompressed to give the original message.

3. RESULTS

We have implemented a graphical barcode system comprising the barcode-generating and the barcode-reading sub-systems. Figure 4 shows an example of a graphical indicium simulating the IBIP (Information Based Indicia Program [9]) postal indicia for electronic stamps. The indicium embeds postage information, including the date, time of printing, zip codes of both the source and destination cities, postage amount and account number, etc. The embedded information includes a digital signature that can be used to verify the integrity and the authenticity of the indicium.
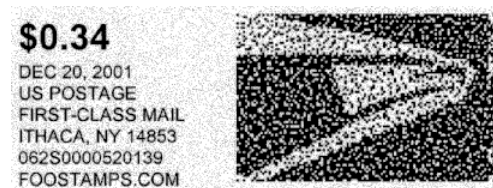

Figure 4: An example of Graphical Indicia.

Currently we use RSA as the digital signature algorithm [8]. However, the efficiency of the system may be improved by using Elliptic Curve algorithms such as ECDSA [10], which provide equivalent cryptographic strength with a smaller key size.

The primary emphasis in tuning the system parameters was fidelity. Performance data cited below refers to an accurate decoding probability of more than 99% for non-deformed graphical indicia. Fidelity is independent of the type of printer and scanner (office type quality). It is also independent of the base image, as long as it is less than 1.5" in dimentions. Larger indicia may contain non-separable deformations, whose correction is out of the scope of this paper.

Robustness to deformations is hard to quantify, and is heavily dependent on the implemented error correction. Thin stripes, for example pen lines across the indicium such as depicted in Figure 5, will usually not cause decoding failures, unless the stripe covers one of the fiducial marks located at the corners of the indicium.
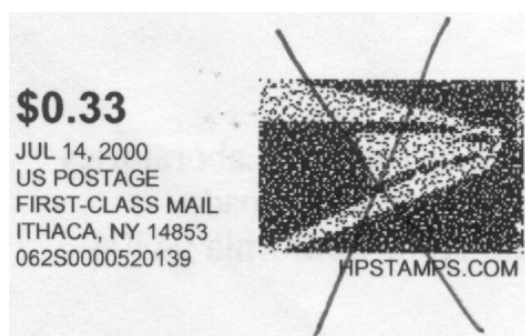

Figure 5: A deformed graphical indicium (decoded correctly).

The typical capacity of a graphical barcode is roughly a quarter of the dot density. For example, in 100 dots-per-inch (dpi) printing, each square inch of the barcode contains 10,000 dots, capable of encoding a theoretical maximum of 10,000 bits of information. In the above example we employed a 16 to 31-bit BCH [11] code correcting for 3 errors, and a 5 bit for 9 pixel graphical modulation scheme [4], resulting in a capacity of 10,000*(16/31)*(5/9) = 2,867 bits, or about 350 Bytes per square inch. Improved performance is expected for higher dpi, better error correction codes, and larger modulation templates.

5. DISCUSSION AND SUMMARY

The basic trade-off in graphical information embedding is a three-way trade-off made between fidelity, capacity and aesthetics. Graphical barcodes differ from image watermarking in the sense that maintaining aesthetics (image quality) is the priority in watermarking whereas capacity (the number of information bits per square inch) is the main goal of graphical barcodes. Nevertheless, in

the system described above we have placed message fidelity as the first priority.

The proposed system decodes graphical barcodes printed in 100dpi at a capacity of 350 Bytes per square inch. Graphical barcodes printed at 85dpi (capacity of 250 Bytes per square inch) are robust to two consecutive copying cycles by a standard office copier.

Future work will include integrating halftone algorithms (e.g., error diffusion [12]) to improve the appearance of the graphical barcode to make it look more like a grayscale image.

5. ACKNOWLEDGEMENTS

6. REFERENCES

[1]   http://users.skynet.be/dje/codebar/

[2]   http://www.adams1.com/pub/russadam/stack.html.

[3]   D. L. Hecht, Embedded Data Glyph Technology for Hardcopy digital Documents, *SPIE Conference*, Vol. 2171, pp. 341-352, 1994.

[4]   D. Shaked, A. Levy, Z. Baharav, and J. Yen, "A Visually Significant Two Dimensional Barcode", *HPL TR 2000 164R1*, December, 2000.

[5]   D.S. Bloomberg, "Reading digital data on paper in iconic text, SPIE Conference", *SPIE Conference,* Vol. 3305, pp. 194-207, San Jose, CA, January, 28-29, 1998.

[6]   J. Rosen and B. Jarvidi, "Hidden images in halftone pictures", *Applied Optics*, Vol.40, No. 20, pp. 3346-3353.

[7]   D. L. Hecht, "Printed Embedded Data Graphical User Interfaces", *IEEE Computer*, March 2001.

[8]   RSA Cryptography Standards RSA Laboratories, PKCS #1 v2.0, October 1, 1998.

[9]   US Postal services, Information Based Indicia Program, http://www.usps.com/postagesolutions/programdoc.html.

[10] ANSI X9.62-1998, *Public Key Cryptography For The Financial Services Industry: The Elliptic Curve Digital Signature Algorithm (ECDSA)*, American Standards Institute, 1998.

[11] G. C. Clark, and J. B. Cain, *Error correction coding for Digital Communications*, Plenum Press, New York, 1982.

[12] N. Damera-Venkata and B. L. Evans, "FM Halftoning Via Block Error Diffusion", *Proc. IEEE International Conference on   Image Processing*, pp. 1081-1084, Thessaloniki, Greece. Oct. 2001.