PiCode: 2D Barcode with Embedded Picture and ViCode: 3D Barcode with Embedded Video*

Innovative System for Transmitting Data from Display to Camera

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ABSTRACT

As 2D barcodes become more and more popular, their new applications, like mobile marketing, give a strong motivation for embedding visual information in them. Information stored on a 2D barcode, being printed on paper or shown on a display device, can be delivered to people via a camera phone with suitable decoding software. The barcoding system can be viewed as a communication system with key functional modules, including channel coding, modulation, channel estimation, demodulation and channel decoding. By applying advanced communications principles, a way to integrate a picture into a 2D barcode (called PiCode) is developed. By extending the idea, a way to integrate a video clip into a series of 2D barcodes (called ViCode) is also developed. To realize PiCode and ViCode, new modulation and demodulation schemes are designed. Based on our channel estimation technique, a new decoding scheme for low-density parity-check codes is devised to provide more robust error rate performance than traditional 2D barcodes. A US patent and a Chinese patent have already been filed based on the innovative methods developed for PiCode.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communication

General Terms

Algorithms, Human Factors, Performance, Reliability

Keywords

2D Barcode, 3D Barcode, Embedded Picture and Video, Encoder, Decoder, Display-Camera Communication Channel

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1. INTRODUCTION

Recently, QR codes appear everywhere not only for inventory, but also for mobile marketing. A typical scenario of the the latter application is that a company logo is embedded in the centre of a QR code in order to promote the company brand to potential customers. Unfortunately, the logo in the QR code is often too small to see and the brand image it represents may even be distorted in order to be fit it in the small area. Therefore, it is highly desirable to design a 2D barcode with perfect integration of the code and the picture. This motivates us to develop a new kind of picture-embedding 2D barcode, called PiCode. A US patent [1] and a Chinese patent [2] have already been filed based on the innovative methods developed for PiCode. Further extending the concepts behind PiCode and 2D barcode in general, we also investigate new ways to increase barcode storage capacity by developing 3D or video barcode, which roughly refers to a video series of 2D barcodes, and to embed in it a low-resolution video clip, called ViCode. Our design approach is based on the interpretation of a barcoding system as a 2D communication system with an image processing frontend so as to draw inspiration from advanced communications theory.

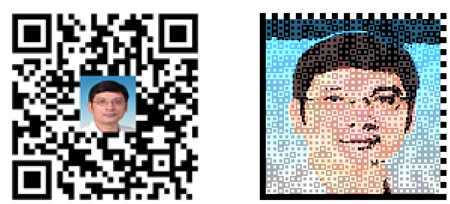

Figure 1: QR code with embedded picture (Left) and PiCode (Right)

1.1 PiCode

The PiCode system mainly includes two parts: i) modulation & demodulation; ii) channel coding. Some barcodes use color to store more information [3], but we use color in barcodes to deliver visual information to human. The first part is about how to add visual information in the barcode and how to recover the stored data from the barcode. Existing 2D barcodes, like QR code and Data Matrix code, usually use black and white square modules to modulate the data bits, which present no meaningful visual information to human. Our approach is to use color in 2D barcode represent the color of a modified version of the embedded image while the data bits are used to adjust the intensity of the embedded image. This process unavoidably induces additional distortion and therefore improving system robust is one of our design emphases. The second part describes the methods adopted for channel estimation, low-density parity-check (LDPC) code and the associated log likelihood ratio (LLR) assignment for iterative decoding. They aim to improve system performance and response time relative to existing barcodes. We have already set up a PiCode demo website at `http://www.picode.info`.

1.2 ViCode

The MIT Media Lab reported a very fast display-camera transmission system by ultilizing the idea of 3D barcode (also called video barcode) with a professional camera, an extra-high resolution display and high-performance computational devices [4], and this proved the huge potential of 3D barcode. For a practical mobile phone platform, another 3D barcode demo was built which can achieve a transmission rate of around 2Kbps [5]. As an extension of PiCode, our ViCode is the first ever attempt to embed a video clip in a 3D barcode which can transmit data at a very high rate using commonly available mobile phones. ViCode is ideal for mobile applications which require higher storage capacity than what 2D barcodes can ever provide, such as storing a brochure, a ringtone, a photo, an app file, and so on. The data storage capacity of ViCode is unbounded because of the extra time dimension and the data transmission rate of our existing implementation is already exceeding 100Kbps. Our demo video is available at `http://youtu.be/rqxHDH2EtVY`.

2. PICODE SYSTEM

2.1 Modulation & Demodulation

For modulation, the embedded image is first converted to a gray scaled one, and resized to have an aspect ratio of 1:1 (i.e., a square shape). In the embedding process, a module, which refers to one of the many small squares composing a PiCode, is used to represent a single bit of the encoded data. Each module is realized by choosing one of two pre-defined tilting patterns according to whether the data bit is 0 or 1.

The gray level of the modules may be heavily distorted in the barcode image captured by a camera. The thresholding detection method commonly used in existing barcode system may not be sufficient in our case. In general, it is difficult for the demodulator to determine the threshold for deciding whether data is 0 or 1 in the presence of severe distortion. The decoding performance is sensitive to the choice of the decision threshold and may be significantly degraded due to the choice of mismatched threshold.

Before the demodulation step, we first detect the finder pattern of the 2D barcode and synchronize each data block based on the timing pattern. By using tilting patterns composed of two concentric squares with different gray levels, the demodulator can decide whether the data bit is 0 or 1 from the differential gray level between the inner and outer parts of a tilting patten, without the need of estimating a threshold. In this way, reliability is improved with less complexity.

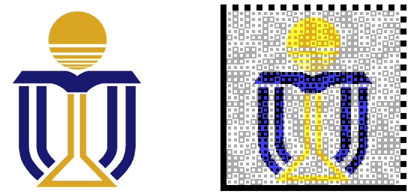

Figure 2: Original picture (Left) and its associated PiCode (Right)

2.2 Channel Coding

PiCode uses soft decoding, instead of the information lossy hard decoding widely applied in existing barcode systems. The demodulator estimates the histogram of intensity difference between the inner and outer parts of every module. Since there are only two tilting patterns, the histogram typically show two peaks. From the histogram, the channel parameters and hence the LLR can be estimated. For example, by assuming the additive white Gaussian noise channel model, the distributions of the aforementioned intensity difference conditioned on the data bit, whether it is 1 or 0, are symmetric. Hence the histogram can be divided into two symmetric parts. By calculating the mean and variance of each part, the LLR of each symbol can be estimated. To realize this soft decoding advantage, we adopt a regular LDPC code with iterative decoding. RS code is famous for its burst error correction capability. However, it is not ideal for random bit error correction because one bit error suffices to cause a multi-bit symbol error. Since the major distortion to the aforementioned intensity difference between the inner and outer parts of every module is induced by edges and sharp changes in the embedded picture, the errors occurred in PiCode are closer to random errors, instead of burst errors. Compared with the Reed Solomon (RS) code that is used in QR code and Data Matrix code, LDPC offers a distinctive performance advantage in terms of bit and block error rate. For barcode decoding, the image capturing and decoding processes are repeated until the first decoding success. Hence, a lower block error rate also translates to a shortened average response time in our PiCode system.

3. VICODE SYSTEM

3.1 System Structure

ViCode can be viewed as a 3D barcode extension of PiCode. As a 3D barcode, ViCode can store much more information than any single 2D barcode because of the added time dimension. In addition, ViCode can also show an embedded video clip or animation, which is ideal for attracting consumer's eyeballs in mobile marketing applications.

The ViCode system produces, instead of a single barcode image, a series of 2D barcodes, which can be shown as a video clip or even a video stream. The camera then captures each frame of ViCode and decode these frames in combination, which allows a much higher data capacity than decoding frame by frame. To achieve good performance, the inter-frame and intra-frame channel coding should be optimized. Advanced communication techniques including Orthogonal Frequency Division Multiplexing (OFDM), LDPC and maximum distance separable (MDS) code, are applied to make the system sufficiently robust and fast.

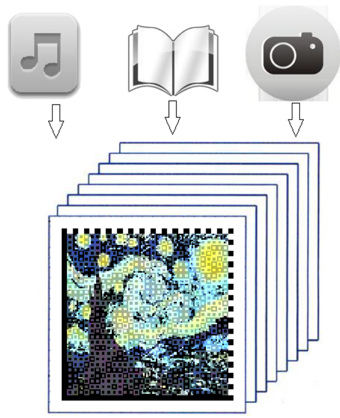

Figure 3: A ringtong, a brochure, a photo, and so on can be stored in ViCode which can be later retrieved using a mobile phone conveniently.

3.2 ViCode Encoder and Decoder

3.2.1 *ViCode Encoder*

The function of the ViCode encoder is to convert a information bitstream and a video clip into a ViCode. Firstly, the bitstream is encoded using a LDPC code. Then OFDM is used to modulate it so as to facilitate accurate frequency offset estimation at the decoder. After scaling & quantization, a set of 2D barcodes are formed. Next, inter-frame MDS encoding, which can achieve the capacity of binary erasure channel, is performed. Finally, a video clip is embedded to form a ViCode, which is then showed on a display device.

3.2.2 *ViCode Decoder*

The function of the ViCode decoder is to recover the information bitstream from a video stream (or an image series) representing a ViCode. Firstly, the camera continuously captures a series of images, to which a novel Moiré effect elimination algorithm based on the camera parameters, distance and angle is applied. Then a fast spatial synchronization algorithm is performed. After estimating and compensating the frequency offset, OFDM demodulation is carried out. Next the intra-frame LDPC decoding and inter-frame MDS decoding are employed to retrieve the information bitstream.

4. CONCLUSIONS

Both our PiCode and ViCode can offer excellent performance in the terms of decoding robustness and data capacity, compared with existing 2D and 3D barcodes available in mobile phone platforms. More importantly, they can also provide eye-appealing visual information, such as a picture or video clip, meaningful to people. They are therefore very promising tools for mobile marketing applications. By integrating PiCode or ViCode into a company logo, commodity packages, electronic billboards, digital signage, TV advertisement, and so on, it can effectively connect potential customers to commercial products. In the near future, when Google glasses become popular, PiCode and ViCode may appear everywhere because they can deliver various form of data to people at no (or very low) cost while they are simply looking at a PiCode or ViCode in the guise of an eye-appealing picture or video clip.

5. REFERENCES

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APPENDIX

A. DEMO SETUP

A.1 Equipment to be used for the demo

An exhibition stand, an iPad, an Android phone and two podia to keep them in upright positions.

A.2 Space needed and setup time required

Space: 150cm Height × 40cm Width × 40cm Length
Setup Time: 15 minutes

A.3 Additional facilities needed including power and Internet/wireless access

Access to power for charging an iPad and an Android phone. Wireless access is not necessary.