Demo Abstract: UnseenCode: Invisible On-screen Barcode with Image-based Extraction (Demo)

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***Abstract*—In this demo, we present UnseenCode, an invisible on-screen barcode scheme. We borrow inter-frame embedment method from VLC-based screen-camera communication techniques to achieve invisibility. Unlike existing VLC-based methods, UnseenCode does not require video-based extraction which is more unreliable and computationally expensive on off-the-shelf smartphones when compared to image-based extraction of traditional barcode methods. We design a delicate image-based barcode extraction method based on cross-component correlation of color images. Our demo implementation includes a transmitter running on desktop computers, and a scanner application running on any off-the-shelf Android smartphones. We would like to exhibit the applicability of UnseenCode in the real world.**

I. Introduction

Screen-camera communication is a popular technology in the field of human-computer interaction (HCI). It utilizes commonly available screen devices as transmitters and camera devices as receivers to achieve one-way device-to-device communication. QRCode [1] is the most popular example of screen-camera communication techniques, which uses visible spatial patterns to represent data. However, barcode methods occupy part of the screen to show human-unreadable contents, which is considered obtrusive to human observers. It is desired to design *invisible barcode* to minimize obtrusiveness to human observers.

Several recent works [2]–[5] gain inspiration from visible light communication (VLC). Different from the *intra-frame embedment* scheme of barcode methods, VLC-based methods introduce *inter-frame embedment* scheme, where data is embedded into the temporal dimension of on-screen contents as high-frequency or low-amplitude inter-frame pixel change (in luminance or chromaticity). Such pixel change is completely invisible due to the limited sensitivity of human vision to temporal light fluctuation (flicker) [6]. Additionally, inter-frame embedment has advantages in capacity because of the usage of temporal dimension in data representation.

VLC-based methods are never strong competitors of barcodes in the real world. We attribute the inapplicability of VLC-based methods to the need for video capture and processing on the receiver side. Compared with *image-based extraction* scheme of barcodes, such *video-based extraction* has the following significant drawbacks:

- *(a) High hardware requirements.* The receiver camera must be capable of recording video at Nyquist rate of display framerate, such as 240 FPS (frame per second) for HiLight [2], to capture inter-frame pixel change. High-speed video recording is not supported by most off-the-shelf smartphones except high-end models.
- *(b) Low decoding reliability.* Videos taken by handheld smartphones always suffer from shake, frame drop and other distortions, which are difficult to correct and can greatly impact on extraction accuracy.
- *(c) High time complexity.* Video processing is generally more computationally expensive than image processing, which can be very challenging on mobile devices.

To address abovementioned issues, we propose UnseenCode, a novel invisible on-screen barcode scheme for screen-camera communication that eliminates the need for video-based extraction. It adopts inter-frame embedment from VLC-based methods to achieve invisibility. Specifically, UnseenCode creates a pair of barcode images from the on-screen picture. The pair of barcode images appear the same as the original picture to human eyes in the condition of *flicker fusion effect*. On the extractor side, we investigate the camera exposure process and propose a delicate image-based extraction algorithm that leverages *cross-component correlation* of color images to recover the barcode image.

UnseenCode provides better visual experience than barcode methods, and better reliability and applicability than VLC-based method. We have tested UnseenCode under various screen and camera settings. Experimental results show that UnseenCode can achieve up to 2.5 kbit capacity with less than 5% error rate. In this demo of UnseenCode, we present a transmitter running on desktop computers and a scanner running on Android smartphones to verify the applicability of our algorithms in the real world.

II. Proposed Method

A. Invisible Barcode Embedment

The key technique of invisible barcode embedment is to decompose each frame of on-screen content into two frames that form a *color fusion pair* of the original frame. When the pair of frames are displayed alternately on the screen at high frequency (more than 60FPS), human eyes perceive

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fused content appearing the same as the original content. The decomposed colors are distinguishable to cameras if exposure time is short enough. This general idea of color decomposition has been proposed in VRCodes [4] and Uber-in-Light [5].

UnseenCode only uses X component of CIE XYZ color space for barcode embedment. On-screen frame $X_o(i,j)$ is decomposed into the following pair of frames:

$$\begin{aligned} X_1(i,j) &= X_o(i,j) - \frac{1}{2}\Delta X(i,j) \\ X_2(i,j) &= X_o(i,j) + \frac{1}{2}\Delta X(i,j) \end{aligned} \tag{1}$$

which are fused into $X_o(i,j)$ for human observers due to flicker fusion effect.

Here, we can use arbitrary barcode images as $\Delta X(i,j)$ to represent data. Specifically, UnseenCode uses $45°$ tilted square barcode templates representing binary bits to construct $\Delta X(i,j)$. Fig. 1 shows an example of decomposed frames.

(a) Original image (b) First frame of the fusion pair (c) Second frame of the fusion pair

Fig. 1: Example of generated fusion pair. Here 265 bits are embedded into Lenna's photo

B. Barcode Extraction with Cross-component Correlation

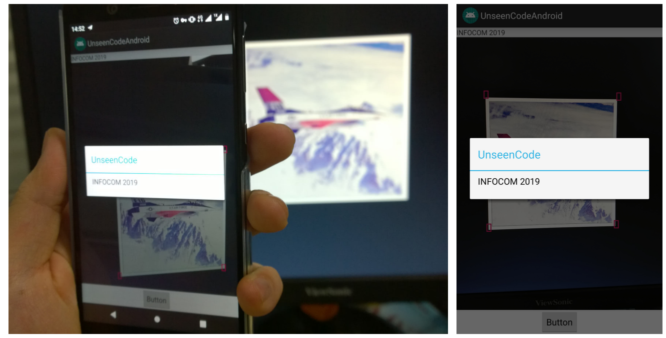
A digital camera captures images via sampling. Suppose that the exposure time of frame X_1 and X_2 is given by $t_1 = \frac{1}{2}t_0 - \Delta t$ and $t_2 = \frac{1}{2}t_0 + \Delta t$ and ignore camera processing and distortions. The captured image X_{cap} is given by:

$$X_{\text{cap}} = t_1 X_1 + t_2 X_2 = t_0 X_o + \Delta t \Delta X \tag{2}$$

To recover barcode image ΔX from X_{cap}, we have to remove the term X_o from X_{cap}, which is unknown to the extractor. We propose to use another CIE XYZ chromatic component Z, which is not changed during the embedment process, to estimate X component. The reason to do this is that there is generally a high correlation between two chromatic components of a color image [7]. Specifically, the barcode image is extracted by subtracting normalized Z component Z'_{cap} from normalized X component X'_{cap}:

$$\Delta X'(i,j) = X'_{\text{cap}}(i,j) - Z'_{\text{cap}}(i,j) \tag{3}$$

Finally, a straightforward correlation-based template matching is applied to $\Delta X'(i,j)$ to determine the embedded bits.



(a) Real-world user operation (b) Screenshot of scanner application

Fig. 2: Usage demonstration of UnseenCode scanner

III. Demonstration

In our conference paper, we have conducted detailed evaluation of UnseenCode under our experimental environment. To demonstration real-world applicability of UnseenCode, we will show a complete UnseenCode implementation, including a transmitter running on Linux computer and a scanner running on Android smartphones, for interested researchers to verify its performance. We apply BCH error-correcting code and CRC error-detecting code to binary data to ensure data integrity under a bit error rate less than 11.4%.

Our scanner provides similar user experience to popular barcode scanners. The user holds the smartphone device over the screen for seconds, and the scanner identifies the UnseenCode image and read out the data. Fig. 2 shows the scene where the scanner decoded the string *INFOCOM 2019* from airplane photo showing on the screen. We have also made a demonstration video available at `https://i-yu.me/unseencode`.

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