PixNet : LCD-Camera pairs as communication links

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ABSTRACT

Given the abundance of cameras and LCDs in today's environment, there exists an untapped opportunity for using these devices for communication. Specifically, cameras can tune to nearby LCDs and use them for network access. The key feature of these LCD-camera links is that they are highly directional and hence enable a form of interference-free wireless communication. This makes them an attractive technology for dense, high contention scenarios. The main challenge, however, to enable such LCD-camera links is to maximize coverage, that is to deliver multiple Mb/s over multi-meter distances, independent of the view angle. To do so, these links need to address unique types of channel distortions, such as perspective distortion and blur.

In this demo, we show how these LCD-camera links can be used to wirelessly transmit information. We present PixNet, an LCD-camera communication system. PixNet generalizes the popular OFDM transmission algorithms to address the unique properties of the LCD-camera link, including perspective distortion and blur. We have built a prototype of PixNet using off-the-shelf LCDs and cameras. In our demo, we will show our prototype communicating data from an LCD to a camera-equipped PC, over multi-meter distances and wide viewing angles.

Categories and Subject Descriptors

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

General Terms

Algorithms, Design, Experimentation, Measurement, Performance

Keywords

Optical Links, Camera, OFDM, Perspective Distortion

1. MOTIVATION AND RELATED WORK

Cameras and LCDs are abundant in today's environment, both in stand-alone form and embedded in laptops, smart phones, and PDAs. This abundance creates an untapped opportunity for using these devices for wireless communication. For example, LCDs mounted on walls or ceilings can encode data into visual frames, allowing camera-equipped devices to download this information. The key feature of such LCD-camera links is that they are interference-free. This is due to the short wavelengths in the visible light spectrum that makes the communication link highly directional. Thus, a multitude of such links can operate simultaneously in a dense area, such as in a conference scenario or a hotspot. Hence, LCD-camera links can potentially evolve into a new wireless technology that is useful in dense high-contention scenarios, similar to how Bluetooth targets low-power scenarios, and whitespaces target long-range communication.

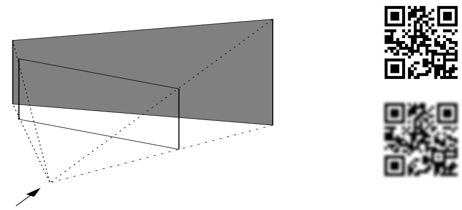
While they offer new opportunities, LCD-camera links bring about new challenges. Specifically, an LCD-camera link exhibits three main types of distortions:

- *Perspective distortion.* Since they operate in the visible light spectrum, LCD-camera links require line of sight. This requirement limits coverage and hence emphasizes the importance of a flexible design that allows an LCD and camera to communicate in the presence of viewing angles. If an LCD and a camera can communicate in the presence of view angles, similar to how a human sees a screen even when he looks at it from an angle, coverage is significantly extended. The challenge is that the image of a rectangular screen becomes a trapezoid when viewed from an angle, as shown in Fig. 1(a).
- *Blur.* Any handshaking or movement while capturing an image or a lack of focus can introduce blur in the image, which causes the pixels to blend together, as in Fig. 1(b). An LCD-camera communication system must be able to deal with such blending and still successfully recover the transmitted bits.
- *Ambient Light.* Ambient light is a source of noise for LCD-camera links because it changes the luminance of the received pixels. This can cause errors in the information encoded in the pixels, resulting in information loss at the receiver.

Thus, the LCD-camera channel needs a new transmission scheme that can handle the above distortions, which are significantly different from the distortions seen in RF channels.

Past work in the area of computer graphics has looked at these problems in the context of 2D barcodes, e.g., QR code [1] or Data matrix [2]. These codes are printed on walls or objects. Users with a camera phone can take a picture of these barcodes, decode them, and obtain a description of the attached object or surrounding space [7, 8]. Barcodes

SIGCOMM'10, August 30–September 3, 2010, New Delhi, India.
ACM 978-1-4503-0201-2/10/08.



(a) Perspective Distortion (b) Blur

Figure 1: Example distortions of the LCD-Camera channel.

however have relatively low information density and must be read at close proximity [3, 5]. In contrast, we focus on developing an LCD-camera link that supports high data rates at multi-meter distances and wide view angles.

2. PixNet OVERVIEW

We present PixNet, a system for transmitting information over LCD-camera links. In contrast to all past work on 2D barcodes, which encode information directly in the visual domain, PixNet encodes information in the *frequency domain*. Such a design is inspired by the popular OFDM transmission scheme, widely used in modern RF technologies. However, unlike existing RF-based OFDM schemes that encode data in time frequencies, PixNet encodes data in two-dimensional spatial frequencies. More importantly, PixNet generalizes OFDM receiver algorithms to deal with the unique distortions of the LCD-camera link. Using PixNet we show that such a generalized frequency-based design provides a unified framework to deal with the distortions in the LCD-camera channel.

PixNet has the following three components:

(a) Perspective Correction Algorithm: A picture taken by a digital camera is a sampled version of the captured object. Perspective distortion occurs when the sampling frequency is irregular. For example, a rectangular screen becomes a trapezoid if the columns on the right are sampled at a lower frequency (i.e., with more pixels) than those on the left (Fig. 1(a)). Since PixNet operates in the frequency domain, it naturally addresses irregularity in the sampling frequencies. We have generalized the OFDM receiver algorithm to allow it to correct irregular sampling and hence correct perspective distortion.

(b) Blur-Adaptive Coding: Approaches that encode bits directly in the visual domain, like 2D barcodes, fail in the presence of blur because the bits blend together. In contrast, since PixNet encodes information in the frequency domain, it is more resilient to blur. Blur, in the frequency domain, translates into attenuation in the high frequencies while the low frequencies remain intact. Therefore, PixNet naturally identifies the frequencies affected by blur and prevents the error from spreading into other bits.

(c) Ambient Light Filter: Approaches that encode information directly in the visual domain have to perform a special preprocessing step referred to as light balancing [4]. In contrast, PixNet operates in the frequency domain. Since ambient light changes the overall luminance, it only affects the DC frequency. Thus, PixNet can filter out the impact of ambient light simply by ignoring the DC frequency.

We have built a software prototype of PixNet and evaluated it using commodity LCDs and cameras. Empirical results show that PixNet delivers multiple Mb/s over multi-meter distances and wide view angles. In comparison with QR code, a state-of-the-art 2D code, PixNet delivers 2x to 9x higher throughput (depending on the distance and view angle). For a complete description of PixNet see [6]

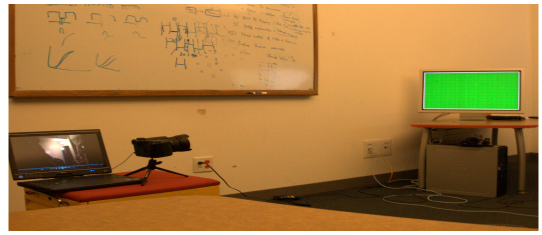


Figure 2: An illustration of our demo setup with an LCD screen (transmitter) and a camera (receiver) tethered to a laptop

3. DEMO

Our demo will show how PixNet can be used to transfer a video file over an LCD-Camera optical link. The video file will be pre-coded as a sequence of frames that the LCD screen will display in a continuous loop. As the LCD screen renders these frames, the receiver will capture and decode them. Fig. 2 shows a visual illustration of our setup.

To demonstrate PixNet's robustness to visual distortions, we will consider a few scenarios in our demo. To show the impact of viewing angle, we will move the camera away from its original center location (with respect to the LCD screen). To demonstrate the effect of blur on PixNet, we will defocus the camera and show that PixNet can still decode the data on the LCD.

We hope that our demo will generate significant interest and encourage the exploration of LCD-Camera pairs as a future wireless communication technology.

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