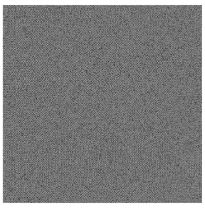
Poster: Secure QR Code Scheme Using Nonlinearity of Spatial Frequency

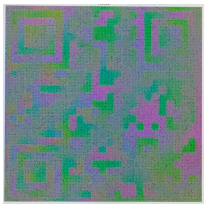
Hao Pan[1], Chuang-Wen (Bing) You[2], Yi-Chao Chen[1], Guangtao Xue[1], Xiaoyu Ji[3]
[1] Shanghai Jiao Tong University, [2] National Taiwan University, [3] Zhejiang University

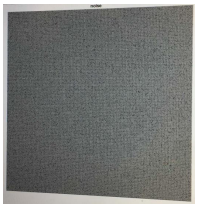
Introduction and Contribution

Goal: Exploting the nonlinearity of spatial frequency in light to encrypt and decrypt QR codes.


(a). Original QR code


(b). *mQR* code: Encrypted QR Code


(c). Picture taken at designated position

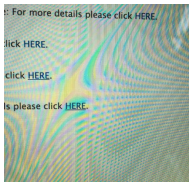

(d). Picture taken at wrong position (off by 15°)

Key Contributions: A novel optical encryption method for QR codes

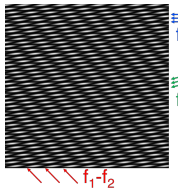
- presents a model to describe Color Filter Array (CFA).
- exploits both the phase and the frequency modulations to generate camouflaging spatial patterns and enables *m*QRCode to work on various communication ranges.
- proposes an effective and robust algorithm to recover QR codes from the captured Moiré patterns in the decryption process.
- prototypes the *m*QRCode system using smartphones and perform extensive experiments to demonstrate the feasibility and limitations of *m*QRCode.

Moiré pattern

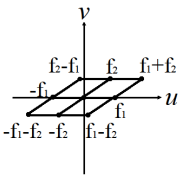
Nonlinearity of Spatial Frequency:



(a) Nonlinear optical interaction when taking a picture of screen using camera



(b) Nonlinear optical interaction of two pattern with frequency f1 and f2



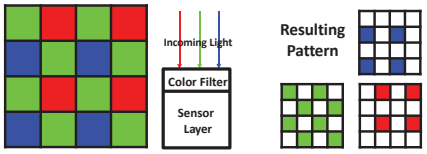
(c) The spectrum of the superposition contains additional frequencies

Assume m is the superposition of two layers m_1 and m_2, the multiplicative model results in the nonlinearity of spatial frequency are shown as follows, when m_1 and m_2 using cosine functions with f_1 and f_2:

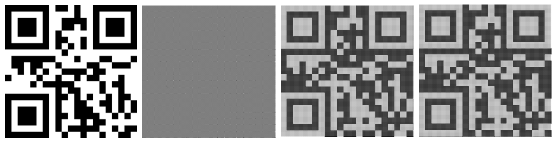
$$\begin{aligned} m =& m_1 \times m_2 \\ =& (a_1 + b_1 cos(2\pi f_1 t)) \times (a_2 + b_2 cos(2\pi f_2 t)) \\ =& a_1 a_2 + a_1 b_2 cos(2\pi f_2 t) + a_2 b_1 cos(2\pi f_1 t) \\ & + b_1 b_2 cos(2\pi (f_1 + f_2) t) + b_1 b_2 cos(2\pi (f_1 - f_2) t) \end{aligned}$$

Encryption

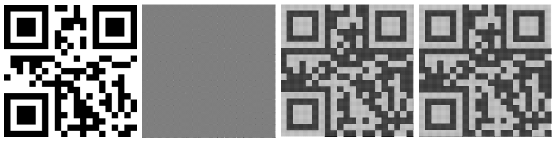
Model CFA:



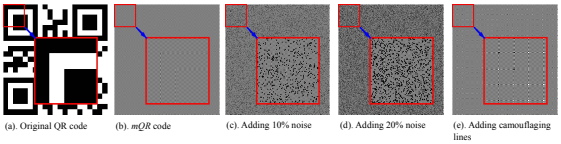
Frequency Modulation:


(a). QR Code (b). Green filter (c). Red filter (d). Blue filter

Phase Modulation:


(a). QR Code (b). Green filter (c). Red filter (d). Blue filter

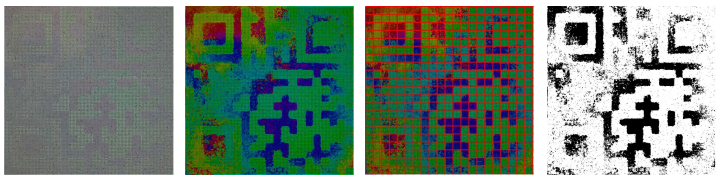
Adding Noise:

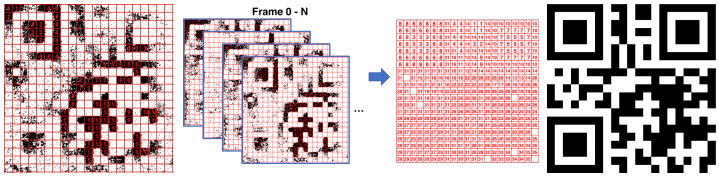

(a). Original QR code (b). *mQR* code (c). Adding 10% noise (d). Adding 20% noise (e). Adding camouflaging lines

***m*QRCode** exploits the nonlinear optical interaction between CFA and the camouflaging pattern to hide QR codes.

- chooses green filter layer to model CFA.
- applies modulation by mapping black and white blocks to different phases.
- modulates the frequency to support different communication ranges.
- adds 10% noise for mQR codes to cancel observable horizontal or vertical lines.

Decryption


(a). *mQR* code taken by camera (b). Enhance saturation (c). Segment into blocks (d). Turn to black and white



(e). Label adjacent blocks with the same color (f). Combine multiple frames (g). Color blocks with black and white

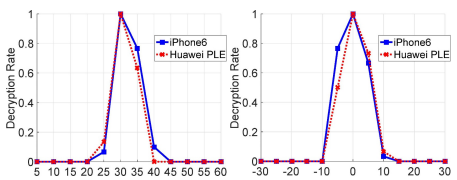
*m*QRCode decryption process:

- converts the RGB images to HSV coordinate and maximize the Saturation dimension.
- segments mQR code by identifying three locator marks and locations.
- separates green from blue/red by thresholding the green channel and turns the image into black and white.
- applies the following filter which has larger weights in the center to classify black and white.

- labels adjacent blocks with the same color.
- combines multiple frames and colors each block.

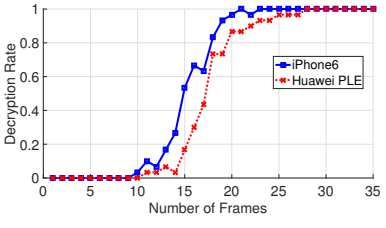
Experiments & Results

The decryption rate of mQR code for 30cm and 0° with different distances and angles:



(a) Impact of distance (b) Impact of angle

Number of Frame vs. Decryption Rate:



Average number of frames required with three displays and nine smartphones: