# IEEE P802.15

# Wireless Personal Area Networks

| | |
|---|---|
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | **Kookmin PHY 6 modes: 2D-sequential color code for ISC** |
| Date Submitted | [March, 2016] |
| Source | Yeong Min Jang, Trang Nguyen, Nam Tuan Le, Mohammad Arif Hossain (Kookmin University) |
| Re: | |
| Abstract | This document gives text detail of 2D-sequential color code (a new color code for Image Sensor Communications). |
| Purpose | Text input to draft D0. |
| Notice | This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. |
| Release | The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15. |

# Table of Content

# 1.0 PHY 6 Layer Operating mode(s)

Optical Camera Communications is introducing three new operating modes.

- PHY 4 accommodates Rolling/Global Shutter Cameras and Low Rate PD
- PHY 5 accommodates Rolling Shutter Cameras
- **PHY 6 accommodates 2 Dimensional Screen Codes**

| PHY 6 Operating Modes | | | | |
|---|---|---|---|---|
| **Modulation** | **Tx Symbol rate** | **Rx Frame rate** | **FEC** | **Data Rate**(5) |
| 2D-sequential code | 5/10 | Rx(fps) ≥ 2.Tx(1) | Inner FEC code(2) Outer code(3) | (symbol rate) x (#_data LEDs) |
| 4 color 2D-sequential code | | | Inner FEC code(2) Outer code(3) | (symbol rate) x 2.(#_data LEDs) |
| 8 color 2D-sequential code | | | Inner FEC code(2) Outer code(3) | (symbol rate) x 3.(#_data LEDs) |
| QR-ISC code | | | level (L) (4) | $R_{QR\ code}$ - (some data for clock transmission) (5) |
| | | | | |

1 Oversampling condition: The sampling rate of camera (fps) must be no less than the symbol rate of transmission. For a rolling shutter camera, the oversampling condition is tight compared to a global shutter camera in order to remove any rolling effected image. For a global shutter camera, the frame rate is no less than the symbol rate of transmission.

2 inner FEC code (TBD): Spatial Error Correction Coding to reduce BER.

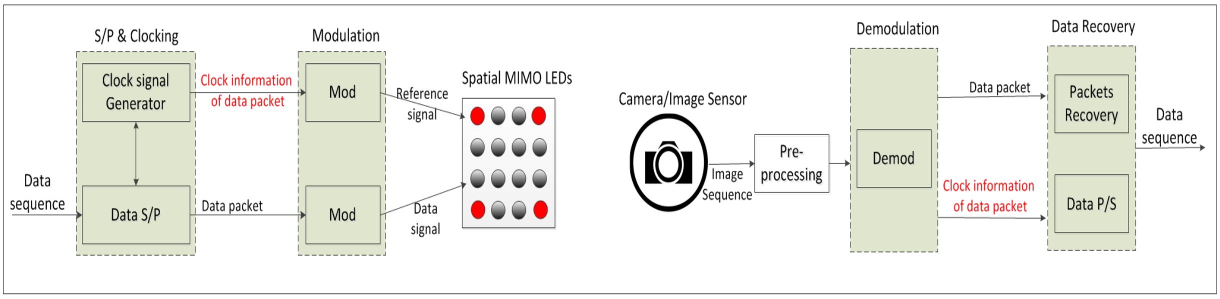
3 outer code (TBD): Due to rolling effect, when the frame rate of camera drops to less than a condition of oversampling, a missed data frame needs an outer code at FCS to be corrected.

4 Error correction level: the lowest level of error correction (level L) is recommended to accelerate the processing time per image.

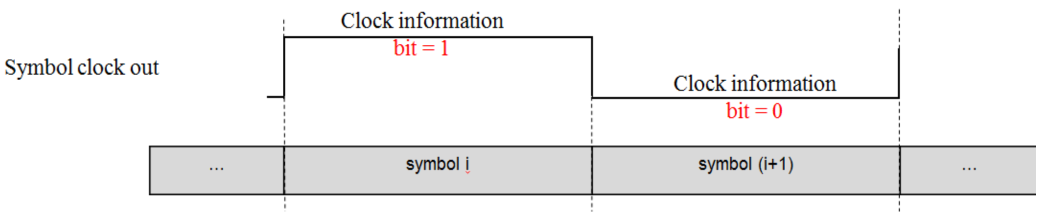
5 QR-ISC data: Same as QR code. However, some data is shared for clock transmission (i.e. asynchronous bits) to help a receiver decoding asynchronously.

# 2.0 PHY 6 specifications

## 2.1 Reference Architecture

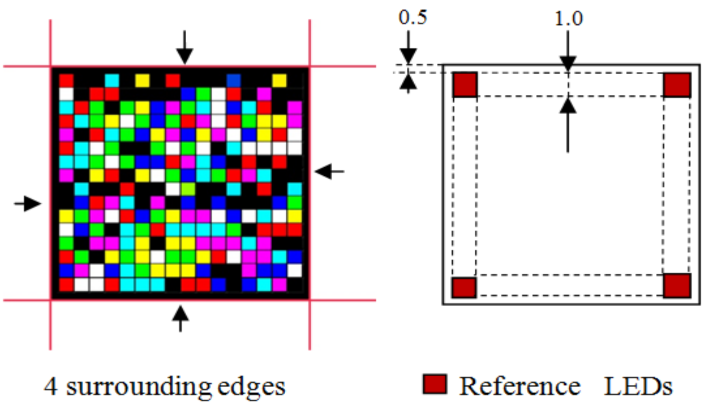



- ❑ clock information (of a data packet/symbol): The information represents the state of a symbol clocked out. The clock information is transmitted along with a symbol to help a receiver in identifying an arrival state of new symbol under presence of frame rate variation.




## 2.2 Transmitter Design

**Transmitter Design:**




**A design of 16x16 LEDs transmitter**

- <u>Reference LEDs</u> (4 LEDs at 4 corners):
  - Transmit *clock information* to help a varying-frame rate receiver in performing *asynchronous decoding*
  - To mitigate the *rolling shutter effect*
- 4 Surrounding lines (high gradient difference):
  - To help a receiver in detecting and extracting LEDs in real-time

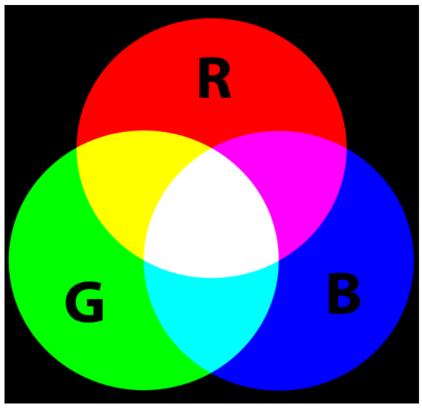
## 2.3 Encoder

<u>A proposed 2D-sequential color code</u>

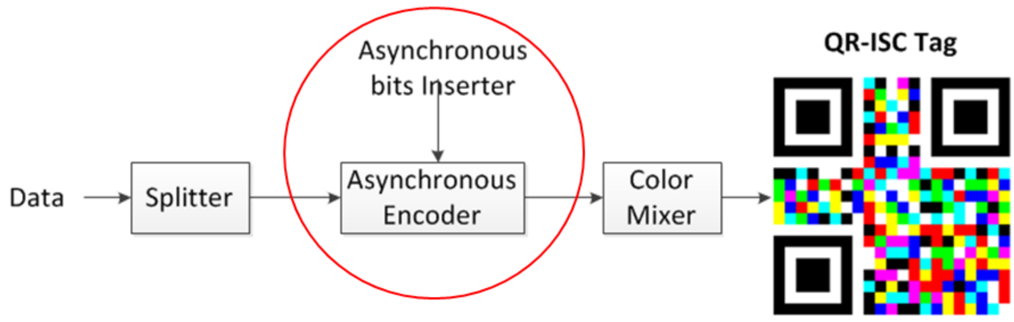
| **Reference LEDs** | Red channel | Clock infor. bits (0 1 0 1 …) | |
|---|---|---|---|
| **Data LEDs** | | data bit "0" | data bit "1" |
| | Red channel | 0 | 1 |
| | Greem channel | 0 | 1 |
| | Blue channel | 0 | 1 |

**<u>8-colors encoding true table</u>**

| 3 bits-Input | Color-Output |
|---|---|
| 000 | Black |
| 100 | Red |
| 010 | Green |
| 001 | Blue |
| 110 | Yellow |
| 101 | Magenta |
| 011 | Cyan |
| 111 | White |



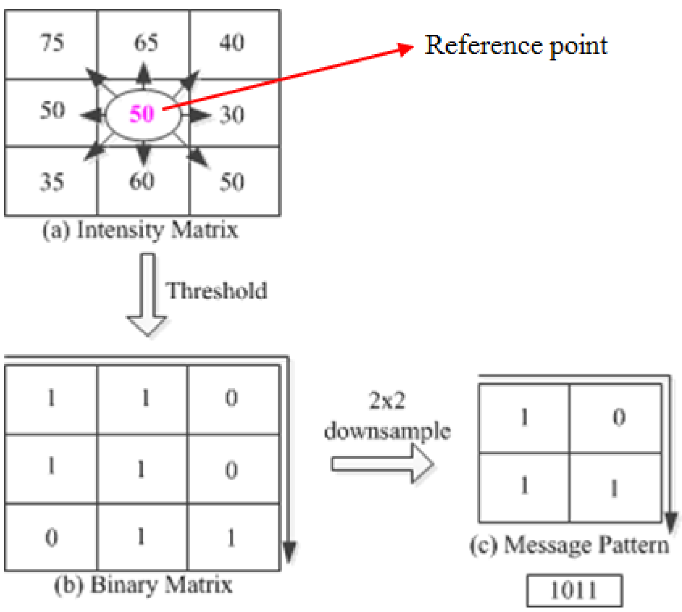
An integration of sequential data into a QR-code interface




QR-ISC Tag is color modulation in Image Sensor Communications (ISC) integrated into QR code. The ISC uses three channels of Red, Green and Blue to transmit data, along with that is the **asynchronous symbols** to support **varying-frame-rate** camera receivers.

- We borrow the format and error correction from QR code standard.
- An asynchronous bits Inserted is need in helping a varying-frame-rate receiver decoding asynchronously.

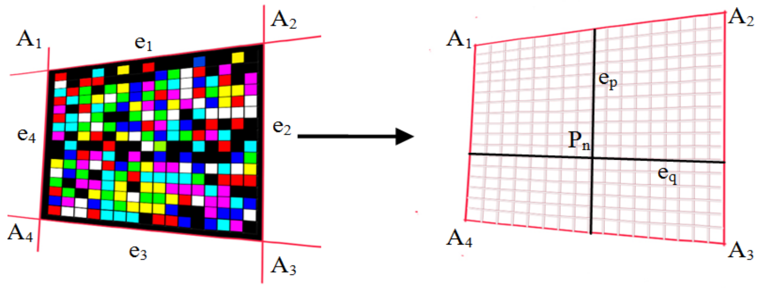
## 2.4 Error Correction




- A spatial Error Correction Coding is need as an inner code
- Outer code is helpful in correcting any error caused by frame rate drop.

# 3.0 PHY 6 Layer Decoding Method (for Kookmin color code)

## 3.1 Perspective Distortion Mitigation




(a) Image and surrounding edges detection

(b) Matrix of middle points of LEDs

**LEDs extraction matrix using line detection under perspective distortion**

**Step 1:** 4-Edges detection using image processing

- Edges are detected by using Hough transform
- The position of 4 corners and matrix positions of LEDs

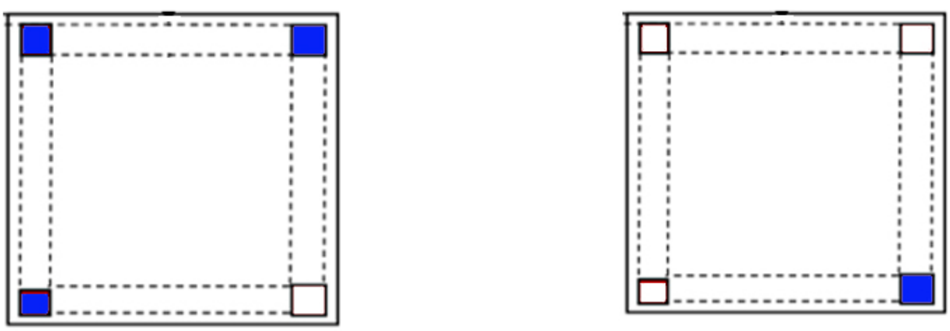
$$A_i(w,h) = e_i \cap e_{i+1};\, with \quad i = \overline{1,\ 4};\ \ e_5 \equiv e_1.$$

$$P_n(w,h) = e_p \cap e_q;\, with \quad p,q = \overline{1,\ 16};\ \ n = \overline{1,\ 256}$$

**Step 2:** 16x16 LED-positions Matrix forming

- Input: 4-corner positions $A_i(w, h)$
- Output: 16x16 matrix of LED-positions

## 3.2 Rotation Mitigation



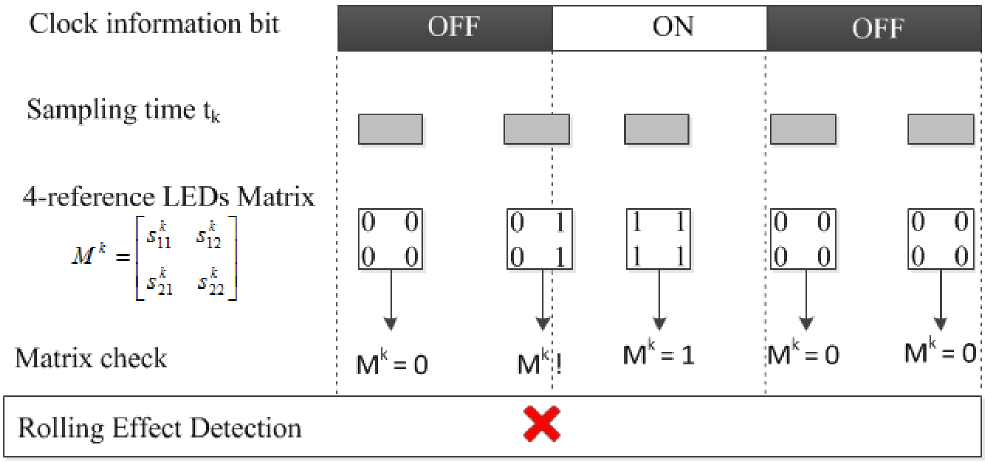
- A blue channel is applied to transmit a signal that allows a receiver in identifying presence of rotation.
- At any time, a state of a reference LED is always different from the other three. The rotation is identified easily by checking those four states of reference LEDs.

## 3.3 Rolling Effect Detection and Cancellation

- ❑ A state-Matrix of 4 reference LEDs at the sample #k: $M^k = \begin{bmatrix} s_{11}^k & s_{12}^k \\ s_{21}^k & s_{22}^k \end{bmatrix}$
  (Notice that the reference signals of those LEDs are transmitted at red channel)

- ❑ Detect the rolling effect in an image:

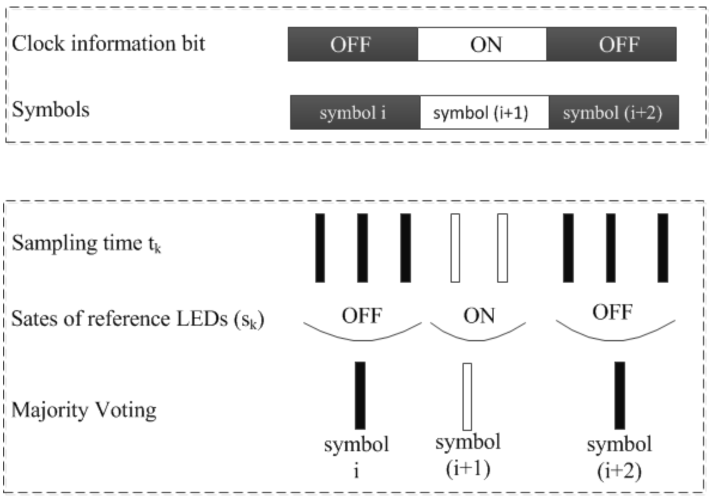
  **- If** ($M^k$ != 0 && $M^k$ != 1) **then** (the image has rolling effect)




**Notice:** The detection is still true under rotation!

## 3.4 Asynchronous Decoding

This scheme is for helping a receiver in decoding under presence of frame rate variation.




- When at least one sample is captured on an interval of a symbol, a majority voting is applied
  - Clock information bit is helpful to identify the group of samples for a symbol voting.