Visible light communication channel with a smartphone screen as a transmitter and color shift keying modulation for access control applications

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Abstract. Smartphones or tablets are a new kind of mobile device that allows developers the optical wireless communication. This enables a low-cost implementation interface with a visible light communication system. The present work aims to implement the access control system based on visible light communication channel with a smartphone screen as a transmitter and color shift keying modulation. The proposed system runs on the Samsung Galaxy notebook tablet to control the light colors emitted by the screen. We used Android Studio to develop the application for access control system. In this scheme, the optical response of the Galaxy screen to 4 color shift keying constellation design based on standard color space is also discussed. The proposed system is validated by experimental tests for access control applications. The results obtained suggest that a bit rate of 100 b/s can be achieved with a 4 color shift keying constellation format. It was concluded that the main advantage of using the Galaxy screen as a transmitter in a visible light communication lies in the low complexity to generate color shift keying modulation and its application on access control system. This can generate opportunities for this method to become realistic on mobile consumer electronics.

1. Introduction
In visible light communication (VLC), it is common to find optical transmitters conforming of a phosphorescent light emitting diode (LED) [1–3], as proposed by the IEEE 802.15.7 standard for optical wireless communication [4]. Phosphorescent LEDs are preferred for VLC due to their low cost, energy-efficient and modulation bandwidth [5]. LEDs have been extensively used in consumer electronics such as tablet and smartphones. Some research papers in VLC using a smartphone flashlight with light emitting diode has been studied [6–8]. VLC using a smartphone flashlight LED is investigated by Giorgio et al [9]. The flashlight can operate to blink at given frequencies (around 50 Hz and data rate of 2 b/s). However, VLC based on the smartphone flashlight as a transmitter has a low bit rate and high latency time because the flashlight is controlled by the Android operating system. On the other hand, other LED technology based on colored light red, green and blue (RGB) LED [10] transmits data in multiple communication bands, using the multilevel modulation scheme as color shift keying (CSK) [11,12]. In CSK, thus encodes data in the instantaneous output color of the RGB LED.

In this paper, we proposed the use a smartphone (Galaxy table) screen as an alternative to design the transmitter of a VLC system using a color shift keying modulation. In this scheme, the optical response of Galaxy screen for 4-CSK constellation design has been presented. We develop an application (APP) in the Android studio platform, to generate 4-CSK constellation. Finally, we proposed an experiment
for access control application to validate a multi-color VLC system based on a Galaxy screen as a transmitter.

2. Materials and method

The implementation of an access control system based on visible light communication channel with a smartphone screen transmitter and color shift keying was carried out in the university laboratory (optics, photonics and artificial vision) of the “Instituto Tecnológico Metropolitano (ITM)” of Medellín, Colombia. A block diagram of the VLC for an access control system is shown in Figure 1. The lighting levels of the external sources were controlled to ensure a VLC system free of interferences. The distance between transmitter and receiver was 3 cm.

The transmitter is composed of a Galaxy Note 10.1 (2014 edition) with high wide quad extended graphics array (WQXGA) (25600 x 1600) resolution. We developed an application (app) in the android studio platform, to generate CSK constellation. We design the 4-CSK constellation considering the optical response of Galaxy screen and the Euclidean distances between color points on the CIE 1931 color space [11,13]. The central wavelength associated with the RGB light pixels of the Galaxy screen was measures with the RL1 optical spectrometer manufactured by ASEQ instruments. The Galaxy screen reproduce the constellation points or symbols in the CIE-1931 color space. Then, the produce VLC RGB light signals will travel different free space transmission distances and is detected by an optical sensor. The receiver consists of an ADJD-S311 color light sensor evaluation board. The ADJD acts as the 4 channels red, green, blue and clear (RGB+Clear) filters and analog-to-digital converter front end. Then, the ADJD was connected to an Arduino UNO microcontroller (MCU) via 2-wire serial interface. The Arduino UNO is a MCU board based on the ATmega328P commercially available with 16 MHz quartz crystal and low power consumption. We implemented an algorithm on the MCU to detect the 4-CSK symbols using a model of the M-CSK-based VLC channel [11]. Then, the capture RGB light digital signal will be transferred to the personal computer (PC) for signal analysis using Matlab® program. Finally, we proposed a VLC 4-CSK experiment to validate an access control system.

Figure 1. Proposed VLC-CSK based on a Galaxy screen transmitter and an RGB sensor receiver for an accesses control system.

3. Results and discussion

The result obtained during the process of optical response of the Galaxy screen is presented below. This optical response of the Galaxy screen enables us to carry out an analysis from the color standpoint, where the peak wavelengths mark the vertices of the color triangle in the CIE-1931 space [13], as show in Figure 2. The color coordinates \((x, y)\) associated with the RGB pixels of the Galaxy screen are \((x_R = 0.71, y_R = 0.28), (x_G = 0.0224, y_G = 0.779), (x_B = 0.15, y_B = 0.016)\) with peak wavelengths \(\lambda_R = 640\ nm, \lambda_G = 512\ nm, \lambda_B = 448\ nm\). The 4-CSK constellation symbols and binary data encoding was S1= 00b, S2=01b, S3=10b and S4=11b. We reproduce all symbols with Galaxy screen colors light generators, where the S1, S2, S3 and S4 correspond to red, green, blue and white light respectively.

The experimental result of the VLC based 4-CSK and Galaxy screen as a transmitter applied to an access control system are presented below. We designed an algorithm on microcontroller for color decoding in terms of optical power received of the sensor color (optical power is interpreted as a function of photocurrent signals). The first step was compensating the photocurrent signals \(I_{\text{lin}}\) for channels i =
R, G, B and symbols \( m = 1, 2, 3, 4 \) using an optical gain matrix \( H \) [11] to estimate the vector of RGB optical powers \( \vec{P}_{l,m} \) with Equation (1).

\[
\begin{bmatrix}
\vec{P}_{R,m} \\
\vec{P}_{G,m} \\
\vec{P}_{B,m}
\end{bmatrix} =
\begin{bmatrix}
131.7 & 93.9 & 24.8 \\
32.1 & 325.6 & 93.5 \\
20.8 & 93.9 & 228
\end{bmatrix}^{-1}
\begin{bmatrix}
\vec{r}_{R,m} \\
\vec{r}_{G,m} \\
\vec{r}_{B,m}
\end{bmatrix}.
\]

(1)

The second subprocess was the transformation of the RGB optical power space \( \vec{P}_{l,m} \) into color space \( (\vec{x}_{p,m}, \vec{y}_{p,m}) \) that corresponds to the color coordinates for each symbol \( \vec{S}_m \) through the expression in Equation (2).

\[
\begin{bmatrix}
\vec{x}_{p,m} \\
\vec{y}_{p,m} \\
1
\end{bmatrix} =
\begin{bmatrix}
0.71 & 0.0224 & 0.15 \\
0.28 & 0.779 & 0.016 \\
1 & 1 & 1
\end{bmatrix}
\begin{bmatrix}
\vec{P}_{R,m} \\
\vec{P}_{G,m} \\
\vec{P}_{B,m}
\end{bmatrix}.
\]

(2)

We decode the binary data represented by each symbol \( \vec{S}_m \) of the constellation 4-CSK. The correspondence of each symbols \( \vec{S}_m \) estimated with the reference symbol \( S_m \) of constellation 4-CSK was determined using the measurement of minimum Euclidean distance \( d_m \), as show in Equation (3).

\[
d_m = \min \| \vec{S}_m - S_i \| \text{ for } i = 1, 2, 3, 4
\]

(3)

In Figure 3 the received symbols for the RGB channels experiment are shown for 4-CSK constellation. A total of \( 1 \times 10^3 \) symbols where randomly generated and transmitted for the Galaxy screen device. We experimentally found 50 baud-rate maximums for the Galaxy screen. Therefore, the data throughput is lower data rate (100 b/s for 4-CSK). We consider that it could be a functional VLC system, because the main application is in low data rate sceneries (access control system), so the bit rate is not critical.

The constellation can be recognized, as shown in Figure 3. This is because the light levels of the external sources were controlled to ensure a VLC system free of interferences. Additionally, the distance between transmitter and receiver was constant for access control application. However, we consider that the dispersion of chromatic points the all symbols are degraded by additive white Gaussian noise (AWGN), backlight Galaxy screen and values of the optical gain matrix \( H \) to estimate the vector of RGB optical powers. Such stimulations may be causing a symbols deviation of that mapped in the 4-CSK constellation CIE-1931 color space. Nevertheless, we consider that the low dispersion of the symbols CSK in our proposed system, allowed us to validate the access control application. We design 10 ID for users considering the next scheme “2 start symbols + 4 symbols for userID+2 stop symbols”, for our
access control application. This scheme is similar to that used for the Universal Asynchronous Receiver-Transmitter (UART) for serial communication based on communication protocols like RS-232. We consider this proposed approach is convenient for the receiver to decode the symbols, because the asynchronous communication is transmission of data, generally without the use of an external clock signal.

![Figure 3. Received symbols for RGB channels for 4-CSK constellation.](image)

We experimented with different user IDs for an access control system based on VLC and 4-CSK modulation. Each ID was validated under the same laboratory light conditions. According to Figure 3, four reference symbols (redpoint) need to be obtained before the performance for 4-CSK can be analyzed. Such procedure is performed considering the optical response of the light source (Galaxy screen for this research work). Additionally, using a high-resolution RGB sensor to detect CSK symbols is recommended for low dispersion on M-CSK constellation. The throughput of the constellation size (4-CSK) can be improved by higher constellations (> 4-CSK) using a heuristic optimization algorithm [11].

4. Conclusions
In this study, we implement a novel design of a VLC system based on CSK modulation with a smartphone screen transmitter and an RGB sensor as a signal detector for an access control application. We design the 4-CSK constellation considering the optical response of Galaxy screen and the Euclidean distances between color points on the CIE 1931 color space, suggesting possible factors that generate dispersion of the chromatic points the all symbols. Given the low dispersion of the symbols, we can say that the one of the potential application scenarios is the “access control system”, similar to radio frequency identification.

The main advantage of using the Galaxy screen as a transmitter in a VLC system lies in the low complexity to generate CSK symbols and the technological convergence with smartphones. This can generate opportunities for this method to become realistic on mobile consumer electronics.

Future works include evaluation of multilevel modulation 16-CSK or 32-CSK considering a heuristic optimization algorithm (particle swarm optimization) for design constellation in the color space, to improve VLC system performance. This approach can be used to increase VLC data throughput (>100 b/s).

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