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OpenCV 라이브러리 기반 FSK OCC 시스템의 성능 측정

Performance of OpenCV Library for FSK OCC System

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ABSTRACT

With the development of semiconductor especially, nano technology, image processing is playing an important role in the multimedia display industry. It is also one of the most considered research topic which has been combined with the industrial production quickly with the on-chip integration. As an important step in optical camera communication (OCC) operation, image processing makes decision for the reliable system. There are some open-source computer vision libraries for image processing applications. One of the earliest libraries to be considered by many researchers is OpenCV. In this paper, we will propose a new OCC system based on frequency shift OOK modulation and evaluate the performance of proposed system based OpenCV library for a real time application on android smartphone scenario. From the measurement on consumption time, accuracy for every phase, we make a comparison with other implements to prove the efficiency of OpenCV library.

Key Words : Visible light communication, optical camera communications, frequency shift keying, smartphones, camera API, OpenCV library

Ⅰ. Introduction

The camera is integrated in a variety of devices such as phones, cars for entertainment applications or safety needs. Considering as an extension of visible light communication, OCC(Optical camera communication) has the potential commerce in development of optical wireless communication which is deployed with many application scenarios and topologies[1,2]. To be more utilizing the camera's superiority, many researchers have developed camera-based applications such as tracking, object detection. One of the promising techniques due to the development of image sensor and camera business trend is OCC. OCC is an idea which established on camera sensors for receiving data from explicit LED. The data is transmitted from one or multiple LEDs, which used intensity modulated cautiously, can be detected by the camera sensors via a line-of-sight channel. Comparison to other communication technologies, OCC has advantage on development cost, interference, MIMO issues as shown in Table 1.

One of important processing step in OCC operation is region on interest (RoI) of light signal detection and modulation. To achieve high reliable on performance, a good image processing algorithm should be considered. OpenCV is one of the most extended software libraries used in computer vision applications. It is an open source library constituted by a series of C/C++ functions and classes, offers

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many common algorithms to realize image processing and computer vision computing, which can be used to achieve powerful image processing, and to develop real-time applications system. First, to thoroughly utilize the image sensor's hardware capabilities as well as to minimize the time taken to retrieve image data from the image sensor, we configure parameters such as frame rate, shutter speed, output format with camera application program interface (API) to be supported by android Google developer. After obtaining the image data with the long communication distance and desired data rate from the smartphone camera, we used the OpenCV C++ computer science programming library to detect and modulate the data.

This paper presents an OCC system using FSK modulation based on OpenCV library. In the next section, we will explain more detail about what kind of OpenCV's algorithm used in our image processing application. One more thing that is not less important than contour detect algorithm, measure distance between contours or data demodulation, is how to solve error correction problem. In the previous research about image processing for OCC, there are many proposed schemes try to solve the performance of error correction in signal transmission. However most of the methods[3,4] are only theoretically defined and have not been tested practically with long distance data transmission or smartphone cameras which configured fixed frame rate and shutter speed.

Table 1. Technical comparison of OCC

	OCC	VLC	RF
Spectrum	IR, VL	VL	Radio wave
Path loss	Low	High	High
Illumination	Yes	Yes	No
Security	Medium	High	Low
Data rate	Low	High	High
MIMO	Simple	Complex	Complex
Interference	Low	High	High
Cost	Low	High	High

Ⅱ. State of art

2.1 Optical camera communication

In screen-to-camera based topology, the light signal is embedded in array light source transmitter devices such as LCD display and digital signage. The modulation technique includes 2D binary color[5], multicolor [6], QR code[7], screen CDMA[8] and screen OFDM. The data is converted from light level or light waveform to camera image sensor pixel. This topology has an advantage on multiple-input and multiple-output (MIMO) development. Oversampled and under sampled modulation are also used in OCC. Polarization based modulation is used as oversampled for low frame rate camera like Webcam where change of polarization is considered. Subcarrier intensity modulation is known as under sampled modulation. Under sampled modulation offers long distance communication with high data rate and high spectral efficiency. For light-to-camera topology, the transmitter modulates the data with the lighting brightness level. The hardware mostly familiar with LED which can switch the lighting status at high speed. Due to this characteristic, light-to-camera topology can easily overcome the flickering problem. The modulation techniques for this architecture include on-of keying (OOK) with run-length limited (RLL) encode such as Manchester Code, 4B6B, 8B10B[9] and frequency subcarrier[4,10]. The modulation technique for this topology is based on ON-OFF capturing status. The captured lighting status in image sensor represents the binary bit information of embedded data. With traditional OOK modulation, the flickering on illumination can be occurred due to the human eye responsibility.

As an enhancement of OOK modulation for flickering issues and communication range, frequency subcarrier is considered in many applications and scenarios. The binary bits are represented by different of On Off light status. The separation on frequency is defined by the different combination of sampling state. Depending on the image sensor architecture, global shutter and rolling shutter, one captured image frame can include one or multi transmission bits information. The research on frequency subcarrier from most of proposals is mainly focus on the data enhancement issue based on rolling shutter image sensor with high efficient modulation synchronization, frame variation[4,[11] or error correction. Most of research have not addressed deeply the implementation challenges of android smartphone image sensor architecture. In this paper, we analyze and evaluate the performance of frequency subcarrier modulation, frequency shift keying (FSK), on the communication and implementation parameter with OpenCV library. The frame rate variation is occurred due to the variation of resolution and image format on RoI detection processing time. The factor of frame variation from the specific characteristic of image sensor hardware is not analyzed in detail on the point of programming optimization.

2.2 FSK in OCC

In optical camera communication point of view light source is derived with a modulated data signal. In this system FSK digital modulation scheme is used. The binary data is merged with a high frequency signal. Frequency shift keying is the digital modulation technique in which the frequency of the carrier signal varies according to the digital signal changes. FSK is a scheme of frequency modulation. The output of a FSK modulated wave is high in frequency for a binary high input and is low in frequency for a binary low input. The binary 1s and 0s are called Mark and Space frequencies. The transmitter LED flickers according to modulation frequency. Human eyes can catch flicker below 200 Hz. As visual flicker is undesirable modulation frequency should be high than that. Frequencies used for modulation is generally between 200 Hz to 8KHz to support android rolling shutter characteristics.

In the receiver side to extract the data from light receiver should be synchronous with the frequencies. As smartphone camera is matched the exposure duration to get the continuous dark and white strips. Receiver measures the strips widths to find the binary transmitted data.

2.3 OpenCV Library

OpenCV is released under a Berkeley Software Distribution license in 2000 therefore this library is free for either academic or commercial purpose. The OpenCV library is universal for every field on the world, from interactive art, to mines inspection, stitching maps on the web or over advanced robotics. OpenCV has exceeding 47 thousands people of user community and estimated number of downloads more than 14 millions. Nowadays, aiming at easier, more type-safe patterns, new functions, and better implementations for current systems in terms of performance (especially on multi-core systems), OpenCV supports multi programming languages such as C++, C, Python and Java interfaces for Windows, Linux, Mac OS, iOS and Android. OpenCV was designed for computational efficiency with first priority for real-time applications. Built in optimized C/C++ platform, the OpenCV library inherits advantage of multi-core processing. The OpenCV open computing language (OCL) module contain a set of classes and functions that implement and accelerate OpenCV functionality on OpenCL compatible devices of the primary heterogeneous compute platform. OpenCV's application field include: 2D and 3D feature toolkits, egomotion estimation, facial recognition system, gesture recognition, human-computer interaction (HCI). Mobile robotics, Motion understanding, object identification, segmentation and recognition, stereopsis stereo vision: depth perception, structure from motion (SFM), motion tracking, augmented reality.

Ⅲ. Proposed 8-FSK for OCC

By detecting the distance from two adjacent captured image stripes, we can classify the frequency and demodulate the encoding data. This is the basic idea with FSK modulation; however there are a number of practical challenges needed to be solved.

Due to the limitation of frequency separation from illumination frequency band and error control, we proposed 8-FSK modulation for OCC system with the configuration parameters as Table 2. Therefore, we received 3 bits in every frequency. By calculating how many different how many different frequencies we have between two consecutive frequencies, we will either export the data symbol with 4 total frequencies or execute error correction if the mixed-symbol frame occurs as shown in Fig. 1 and Fig. 2. For synchronization control, we have to insert the splitter frequency supporting the system to distinguish which frame will bring the beginning and ending frequency. In this case, frame f2 and f3 contain two transmitted frequencies s1s2 and s2s3 respectively.

FSK OCC modulation uses square wave modulation. One of the best characteristics of square wave is that it only needs two output levels, which avoids complicated driving circuitry and decreases the overall system cost. With rolling shutter sampling, a square wave of a certain frequency transmitted by the light would result in a stripe pattern in the image. In addition, different frequencies correspond to different widths of strips. And most important feature in Fig. 3, the location and the orientation of a camera and how large the light is in an image, this strip width does not change. In other words, the captured stripe pattern is not distorted due to either perspective distortion or physical light shapes. Rolling Light uses different frequencies of square wave to represent different symbols if their corresponding strip widths are

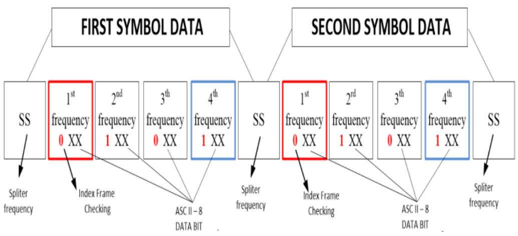

Fig. 1. FSK modulation for symbol format

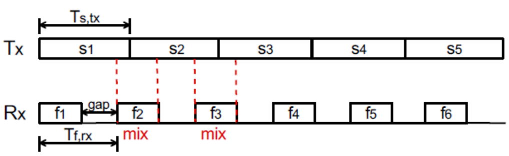

Fig. 2. Mixed-symbol in FSK OCC system

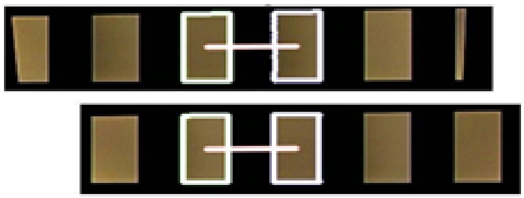

Fig. 3. Strip width of rolling image with same frequency subcarrier at different receiver's position

distinguishable. This is the common FSK modulation used in many communication systems. Let F denote the set of frequencies used for modulation. Then, each symbol can represent $\log_2|F|$ data bits. By increasing the number of frequencies, we can increase the order of modulation, and hence the data rate. The receiving camera can demodulate the signal based on the strip width of the received image and converts it back to the transmitted frequency.

Note that, for a square wave of frequency f, the duration of a complete cycle is 1/f seconds. Therefore, for every 1/f seconds a camera exposes, it should be able to read out a couple of bright and dark strips in the received image. In addition, recall that the time a camera spends to read out a row of pixels is its read-out duration T_r. Therefore, in theory, the strip width can be calculating by:

$$W_{real} = \frac{\frac{1}{2f}}{T_r} = \frac{1}{2fT_r} \quad (1)$$

The strip width derived from the above theoretical equation is a real number. However, in practice, a receiver can only measure the number of rows occupied by a strip W as an integer estimate of W_{real}, and demodulate the symbol by:

$$f' = \frac{1}{2WT_r} \quad (2)$$

The reason is that the readout duration of each camera T_r is usually an unknown parameter. And, in Fig. 4 we take statistic the strip width detected by each different camera for various frequencies of the signal. The figures show that, for a given frequency,

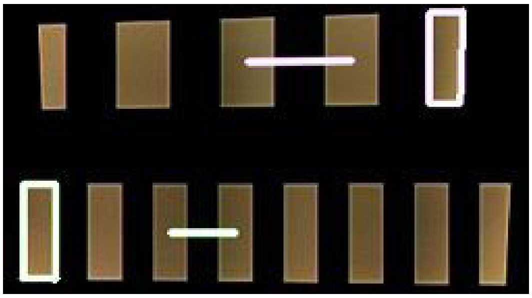

Fig. 4. Strip width of rolling image width different frequency subcarrier

different cameras have distinct read-out duration, and hence could observe a very different strip width. The difference is especially large in the low frequency region, which corresponds to a wide strip. This implies that, a device cannot decode the frequency-modulated signals without knowing the read-out duration, and channel estimation becomes necessary for realizing high-order frequency modulation. Moreover, we should apply the following strategy to pick the lowest and highest frequencies.

Table 2. The system configuration

Parameter	Value
Number of frequencies	8
Synchronization frequency	10 kHz
Optical clock rate	20 Hz
Error correction	run-length encoding
Camera frame rate	20
Shutter speed	8kHz

Ⅳ. Performance evaluation

4.1 OpenCV Operetion for FSK OCC

4.1.1 Get YUV metadata of image frame

YUBV_420_888 format is a generic YCbCr format, capable of describing any 4:2:0 Chroma-subsampled planar or semi-planar buffers (but not fully interleaved), with 8 bits per color sample. In new Camera API, with real time image processing application, we must get the image class from the sensor by YUV_420_888 format instead of JPEG. With YUV format, the processing time will be optimized so much because the system does not need to execute JPEG encoding.

4.1.2 Neglect noise

In this implementation, we use two methods to process the noise: Color to Gray and Thresholding. Image's data obtained are normally color but we know grayscale format are very common and completely appropriate for the implemented task in the paper. Therefore, there is no reason to use more complicated and harder to process color images. For facilitating image processing, the necessary step is usually conversion from color image to gray scale. A grayscale digital image data is a simple format, that is, it contains only intensity information. Images of this kind, also known as black-and-white format are composed exclusively of shades of gray, changing from black at the darkest intensity to white at the brightest. The intensity of gray scale image is often stored as an 8-bit integer data format giving 256 possible different values of gray from black to white. If the levels are evenly spaced, then the difference between successive gray levels is significantly better than the gray level resolving power of the human eye. OpenCV recommends us using the cvCvtColor function to convert the color image to grayscale image. Thresholding converts the color image to a bi-level image. This is the first step in almost of applications involved image processing. We can understand simply that this process looks like a classification between objects and background in an image. It does not detect objects; only separate them from the background. In the process of thresholding, it is very important for us to set the correct threshold value which will determine a pixel as object or background, this step presents pixels whose gray level of 0 indicates the value of the pixels is less than the set threshold value and a gray level of 1 denotes the value of the pixels is bigger than the predefined threshold value.

4.1.3 Detect contours

The function retrieves contours from the binary image using the algorithm[14]. The contours are a useful tool for shape analysis and object detection and recognition. In many research using detect contour function of OpenCV library, it is so difficult to separate and draw a contour clearly as shown in Figure 3. How can we capture the FSK modulation image from LED transmitter without interference? This is the advanced techniques with shutter speed configuration for image sensor. As a result, the captured image from the rolling shutter sensor contains bright and dark strips in widths proportional to the inverse of the frequency.

4.1.4 Calculate distance between two adjacent contours

After detecting contours, we need to calculate the distance between two adjacent contours. OpenCV support for programmer moment function to achieve the calculation easily. Moment is a quantitative measure, popularly used in mechanics and statistics, to describe the spatial distribution of set of points. In most simplistic terms, moments are set of scalars that provide an aggregated measure of a set of vectors. The definition of moments is the same across domains of mechanics, statistics, and computer vision. The set of moments begins with the coarsest description of the set of vectors, and progressively with higher orders, begins to get more sensitive to local structures in the set of vectors. The choice of useful order of moment depends on the data distribution and the sets of vectors to be interested in distinguishing between. The concept of moment in statistics and mechanics has been borrowed in computer vision to coarsely describe an image. For image with pixel intensities I(x, y), the raw image moments M_{ij} are calculated by

$$M_{ij} = \sum_{-\infty}^{+\infty}\sum_{-\infty}^{+\infty} y^j x^i I(x,y) \quad (3)$$

where i, j are order of moments. In a typical image moment computation pipeline, the image I(x, y) is converted to a set of vectors by first computing a gray-scale image and then using a corner or edge detector to reduce the image to a set of salient points. After computing the coordinate of every contour, we will calculate the distance between two adjacent contours as well as the strip weight of contours by using Pythagorean Theorem.

4.2 Performance Evaluation

4.2.1 Processing time and data rate

Since JPEG image format is a compressed image format, application will consume a lot of extracting image data time before convert to Mat format. The mandatory image format when using the image processing functions of the OpenCV library. As compared in Fig. 5 to the processing time of JPEG and YUV_420_888 (a powerful developed image format for applications that use new camera API), instead of the JPEG format, we selected YUV_420_888 image format to minimize the processing time of the application for each frame and increase the frame rate, too. Therefore, significantly increasing the data rate compared to using the JPEG format.

In the experiment based new camera API, with the resolution of 600x800, the average processing time of OpenCV is 22.7ms per frame. Processing time is important factor which effect directly on receiver due to the synchronization loss and buffer overflow. With achieving value, we can achieve 40 fps frame rate, corresponding to 36 bps data rate which is shown in Fig. 6. It ensures fully data rate OCC applications on smartphones. In addition, by varying the distance between the transmitter and the receiver side, the number of stripes in the image will vary inversely with the distance as shown in Fig. 7.

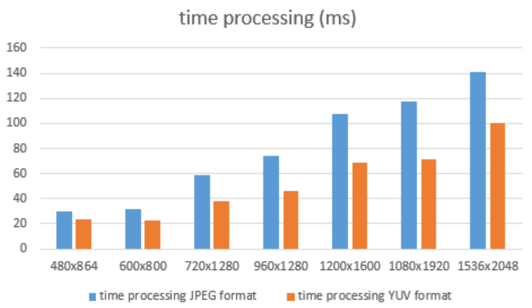

Fig. 5. Time processing comparison for image format

4.2.2 MIMO performance

One of the biggest problems with all OCC applications is data rate. In particular, for applications using FSK modulation, the data rate is very limited. So far, because of this limitation, FSK modulation for OCC applications has not yet been widely used in the market such as QR code. To popularize FSK modulation as well as speeding up data rate, in this paper, we recommend MIMO method. With multiple LED transmitters, we can easily increase data rate many times while image processing time is unchanged. For all other systems, when using MIMO, processing time will certainly increase in proportion to the number of transmitters. But with OCC based FSK, why does not image processing time increase significantly? Since using the OpenCV library, the most important and time-consuming step on the receiver is RoI detection. In this step, OpenCV detects contours in all the pixels of the frame and so, no matter how many LEDs or how many contours in the image, the search time for the contours does not increase much. This is the key characteristic to applying FSK modulation for future communication applications based on image processing.

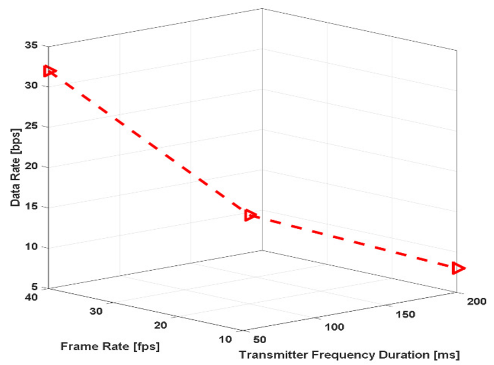

Fig. 6. Data rate, frame rate and transmitter frequency

4.2.3 Distance Performance

With the experiment of 4m distance from transmitter to receiver the image sensor data is shown by Figure 8a, 8b and 8c, there are only 4 strips in the image. But in case 8b, if we calculate distance from first contour to second contour like case 8a and 8c, we will encounter with error because of rolling mechanism limitation. Therefore, to make sure accuracy and avoid complex error correction, we have to always guarantee at least 4 contours for one frequency demodulation and the distance between second contour and third contour calculation. A different meaning from the number of contour is the maximum communication range between transmitter and receiver. For case as shown in Figure 8d, with the captured image at distance 1m, we have several contours and the distance between two adjacent contours still don't change compare with Figure 8a and 8c. It means that with FSK modulation, the position of receiver can change dynamically but the maximum communication range will be recognized when the number of contour is 4.

In our implementation, we configure for image sensor with 600x800 resolution and the maximum communication range is 4m. At the higher resolution configuration, the longer distance we can achieve for communication.

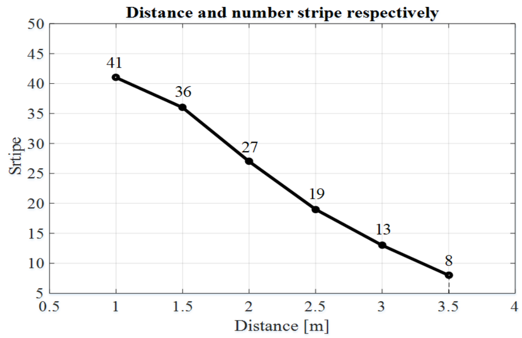

Fig. 7. Number of stripes and link distance

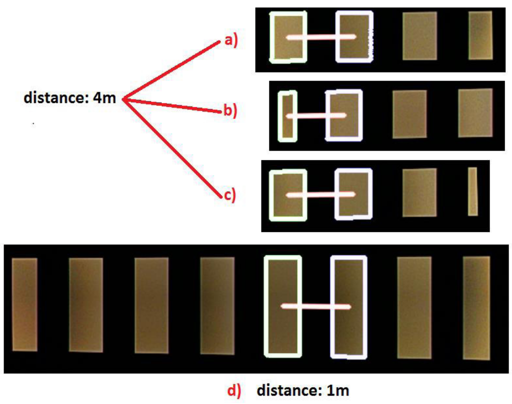

Fig. 8. Communication range affection of FSK OCC

Ⅴ. Conclusions

As a new technology for optical wireless communication, OCC will be a promising business field following the development of image sensor and mobile devices. This paper focuses on the performance of OpenCV library for OCC system with FSK modulation. Beside the analysis on operation configurations, we also proposed and implemented an error correction successfully on android smartphone's rolling shutter camera with the long communication range. With the performance on processing time, image processing functions, OpenCV can be a promising library for future mobile platform to develop commercial Optical Camera Communication based new camera API.

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