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Image Sensor Communication — Current Status and Future Perspectives

Nobuo IIZUKA[†a)], ***Nonmember***

SUMMARY Image sensor communication (ISC), a type of visible light communication, is an emerging wireless communication technology that uses LEDs to transmit a signal and uses an image sensor in a camera to receive the signal. This paper discusses the present status of and future trends in ISC by describing the essential characteristics and features of ISC. Moreover, we overview the products and expected future applications of ISC.

key words: *Image Sensor Communication (ISC), Optical Camera Communication (OCC), Visible Light Communication (VLC), Internet of Things (IoT), Machine to Machine (M2M)*

1. Introduction

Using LEDs not only for lighting but also for data transmission has created an emerging communication infrastructure known as visible light communications (VLC), whose phrase and concept were first proposed by Prof. M. Nakagawa. Figure 1 illustrates a typical conventional case using VLC, where a LED light as a transmitter and a single photo diode (PD) receiver on a portable phone or a personal computer are used.

VLC can be categorized into two types: single photo diode (PD) receiver systems and systems that enable multiple signal reception and tracking using an image sensor in a camera. This type of VLC is known as image sensor communication (ISC). ISC was first proposed by the author [1], [2], who achieved simultaneous reception from multiple point-of-light markers by using an image sensor and patented system that can acquire each position. ISC is also referred to as optical camera communication (OCC) in IEEE 802.15.7r1 [7].

This paper focuses on ISC and presents a current overview of its products, trends, and expected future applications.

The paper is organized as follows: In Sect. 2, the essential ISC model is briefly introduced. In Sect. 3, the features of ISC are discussed, including its technical and market features. In Sect. 4, an overview of ISC products and their architectures are presented. In Sect. 5, current on-going ISC standardization is reviewed, and Sect. 6 provides the future applications of ISC. Finally, Sect. 7 concludes the paper.

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[†]The author is with CASIO COMPUTER CO., LTD., Tokyo, 151-8543, Japan.
a) E-mail: iizukan@casio.co.jp

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Fig. 1 Typical use case of conventional VLC.

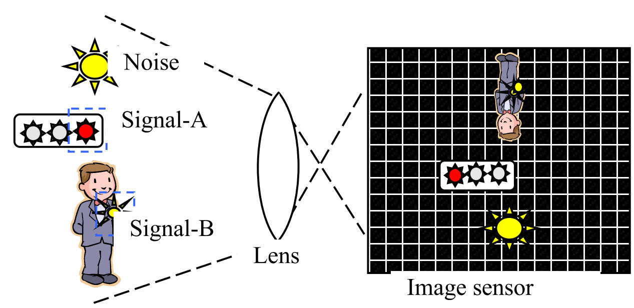

Fig. 2 Typical ISC use case.

2. Basic ISC Model

An essential feature of ISC comes from its two-dimensional PD array structure. Moreover, because of the massive number of pixels, the spatial separation ability of an image sensor enables the simultaneous processing of multiple VLC signals while discarding noise signals such as sunlight and other ambient light sources. As shown in Fig. 2, signal A of a modulated traffic LED light, signal B of a modulated LED badge light on a man, direct sunlight, and reflected background light are all simultaneously projected on the image sensor through the lens. Signals A and B can be filtered while discarding the other noise signals. Moreover, if we focus on a single VLC signal in an image plane, the signal is sampled and processed as a time domain signal. Hence, spatial domain processing, i.e., simultaneous processing of multiple VLC signals in a two-dimensional image sensor plane, and time domain process are incorporated in ISC. Fig. 3 illustrates this incorporation.

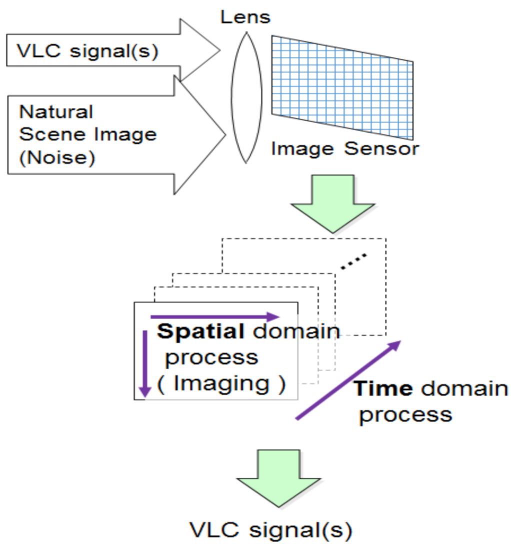

Fig. 3 Essential ISC model.

3. Features of ISC

In this section, we discuss the features of ISC by comparing them with the conventional VLC, which is PD receiving communication (PDC). A receiver in PDC is much simpler than in ISC because it comprises only a single PD.

In PDC, it is necessary to process a value obtained by integrating all of the data signal and noise in the field of view. At the ISC, the structure in which the imaging is spatially divided into a large amount of PD by the imaging lens. This structural difference leads to ISC's features.

3.1 Technical Features

1. Multitarget Tracking
Because an image sensor can be thought of as a PD array with a huge number of pixels, it can track moving multiple targets such as signals A and B in Fig. 2. ISC can simultaneously transmit multiple signals from multiple targets to the camera, which acquires their spatial positions. Although PDC can receive multiple signals with multiple access methods from multiple targets, there is a limit to its ability to comprehend the spatial position relations.

2. Long Distance Transmission
Because the combined structure of a lens and an image sensor is able to extract wanted signals from background noise, increasing the signal-to-noise ratio, even a long distance signal can be detected. It is difficult for PDC to suppress background noise.

3. By-products of ISC.
Most of image sensors are equipped in cameras whose usual functions are recording images and detecting positions of objects. ISC can provide such functions as by-products for users. They are not obtained in PDC.

3.2 Market Features

The use of a camera for communication also has important potential in terms of product design and user experience. First, in ISC, it is possible to implement a VLC function in smartphone cameras. In modern smartphones, a camera is a standard device. Second, in all aspects of industry and daily life, the opportunity to use many types of cameras including monitoring cameras has been increasing. Their expansion with additional communication functions should be expected. Finally, the combination of image and communication functions can be expected in future.

4. Overview of ISC Products and Their Technologies

There is a wide variety of studies on ISC implementation. We review three that are related to their products as well as other studies related to their prototypes.

4.1 Architecture-Dependent Method (ADM)

In order to use an image sensor for communication, there are methods that demodulate ISC signals using operations in the frame imaging hardware. In these studies, a particular image sensor architecture is used.

ID cam [4] is an ISC and it might be positioned as one of ADM. The image sensor has functions of normal imaging and time difference imaging, and fetch of data block and XY coordinate assignment are implemented in the FPGA.

There are various ISC methods depending on a special hardware architecture, but in recent years, the most common of these methods is to use the characteristics of the rolling shutter for sampling. Shutter sampling methods in cameras can be divided into two main methods: rolling shutter sampling methods and global shutter sampling methods. The former method is now used widely in smartphone cameras, video cameras, monitoring cameras, and other types of cameras. The method creates single image by a set of one row scan which is exposed time-sequentially.

As a result, under appropriate modulation frequencies of LED light signals (LED signage, for example), frame rate, and exposure time of the image sensor, the modulated signal is spatially converted to a grayscale pattern image, as shown in Fig. 4.

This conversion from a modulated light signal to the gray (light and dark) pattern image requires a demodulation process.

This method has the advantage that the modulation frequency can be much faster than the frame rate of the camera. For instance, it is possible to achieve data transfer rates of 1 kbps in 30 fps HD-resolution cameras. Flickering induced by such a data rate is not perceivable by human eyes. However, the reception of multiple spatially separated signals and the positioning of these signals are not taken into account.

In addition, the VLC light source must usually be of sufficient size on the image. It is difficult to demodulate data

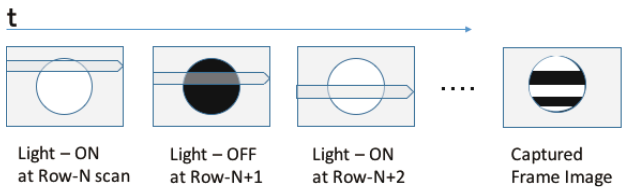

Fig. 4 Rolling shutter method and modulated light.

from a small bright spot. This method requires a large light size like an LED signage for the image sensor.

The image sensors in many smartphone models at present adopt the rolling shutter sampling system. Therefore, this is a practical method that is not limited by frame rate.

4.1.1 Example of ADM Product: Panasonic Corporation's LinkRay

The LinkRay technology [8] is based on ID signals sent by LEDs that form the backlight of LCD signage and similar devices. This technology has been implemented using smartphone application software, and mainly belongs to advertising, public information services or Online 2 Offline (O2O). O2O commerce is a business strategy that draws potential customers from online channels to physical stores.

The LinkRay system works when a user points at an object like LCD signage that is displayed in museums, airports, train stations, sport stadiums, and other similar places and is modulated by information data.

4.2 Architecture-Independent Method (AIM)

This method does not depend on a particular image sensor architecture or shutter sampling method. Here, time series of the frame imaging is the subject of processing. In this method, spatial processing is not used for conversion, but for extraction of the demodulation. The spatial topology of the total image is treated so that it is not lost.

4.2.1 Example of AIM Product-1: Casio Computer Corporation's Picalico

Picalico [5] can use smartphone cameras, PC cameras (in common with the smartphone), and industrial camera platforms.

The system flow of this product is shown in Fig. 5, where an image frame of buildings with a hundred (maximum) VLC signals is input to a camera that is composed of a first-in-first-out (FIFO) buffer, space time discovery filter (STDF), and multi point demodulator (MPD). Both filters were first proposed by the author. When one frame is input, it is convolved with the last few frames in the FIFO buffer.

The STDF is a filter tuned to ISC to process the (three-dimensional) time-series of the image and discovers VLC light sources, eliminating ambient background light noise. It associates a process for each image element (brightness, color, and shape) and the temporal variation of these elements.

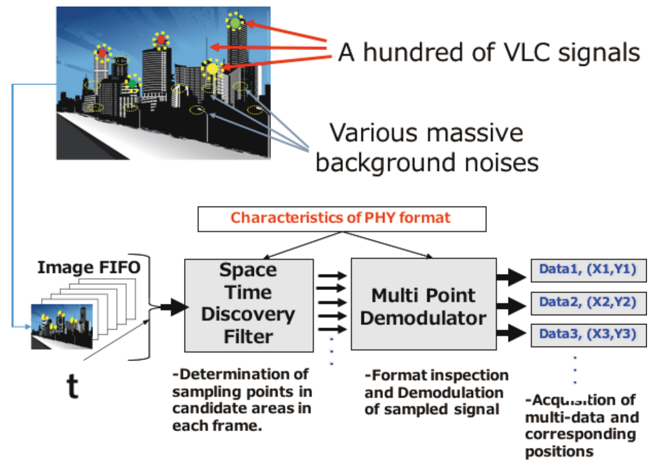

Fig. 5 Picalico processing model.

The MPD is a decoder for multipoint receivers that correspond to multiple pixels, and is able to achieve the multiple transmission of ISCs. The modulation scheme for this product belongs to color pulse modulation.

Because the frame of an image is composed of many pixels (sampling points), data modulated at each LED light object is demodulated at each pixel or over several pixels. The frame rate must be more than double the maximum modulation frequency under the Nyquist condition. Usually, the frame rate is determined by the camera resolution and the system processing capacity.

The current version of Picalico, which is able to process an HD (1280×720 pixel) camera at 20 fps in a mid-range PC, adopts an 8 bps effective bit rate and around 10 Hz modulation frequency. A hundred signals can be received at the same time. The XY-coordinates of the signal on the image are added to the received data stream.

With respect to performance over distances, because the minimum image size of a signal light is one pixel on the captured frame, we can receive data at a distance of more than 50 m from a light signal that is just a few centimeters square (at HD resolution with standard-angle lenses).

The target application of the Picalico is industrial IoT (Internet of Things) as described in Sect. 6-2.

4.2.2 Example of AIM Product-2: Fujitsu Corporation FlowSign [6]

FlowSign might belong to the category of AIM. It uses a type of color modulation method that slightly changes the intensity of red, green, and blue in an LED light source without changing its visual characteristics.

4.3 Other Prototypes

Further, Intel Corporation proposed UFSOOK as a prototype [9]. Although this method might belong to the category of

AIM, its demodulation mechanism is unique. By controlling the phase and timing of exposure, modulation speeds higher than the frame rate are enabled, which addressed the limits of sampling under the Nyquist condition.

Toshiba Corporation presented a dedicated ISC image sensor architecture as a prototype [10]. In their method, the positions of light signals are determined for the next scanning process using AIM. Multiple selected rows that correspond to fast modulated lights are re-scanned with the fast ADM. Hence, this method is a hybrid of AIM and ADM.

5. Standardization

IEEE802.15.7r1 [7] is the task group for VLC in the IEEE802 Standards Committee. The main members of the group are Intel, Panasonic, China Telecom, Kookmin University, and Pure-Lifi. As of September 2016, the draft technical requirements are under discussion. Several ISC methods (called OCC methods) are being discussed in the group.

6. Future Applications

Given the features of ISC, we list some of its unique potential applications below.

6.1 O2O

The action of a consumer at a store (Offline) that influences the Internet (Online) is called O2O business. Figure 6 shows a case of O2O in which smartphone cameras with software installed on them receive a VLC signal from a digital signage. They are able to connect to the corresponding web site through mobile lines. ISC would be a powerful technology in O2O line-of-sight marketing, as shown in Fig. 6.

Note that ISC is better than QR (Quick Response) code in many use cases. It enables longer distance communications and can hide the data source in the LED light without any damage to the aesthetics of the surroundings.

6.2 Industrial IoT (Internet of Things)/M2M (Machine to Machine)

There are many types of indicators emitting blinking lights in factories. They can easily be a VLC transmitter for data transmission.

Although radio waves may not be available, environments needing wireless data transmissions from machines will increase in the future. ISC is acceptable in such a case, as shown in Fig. 7, where LEDs on machines modulated by data send VLC signals (green, blue, and red) to a central camera. The camera can simultaneously receive and track multiple signals.

In some M2M applications, the requirements of data acquisition cycle and latency often allow low-speed data communications, which includes ISC. Further, one of the features of ISC is to find highly precise positional relationships between objects at production sites, as shown in Fig. 8.

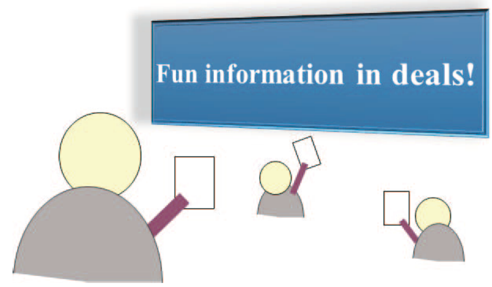

Fig. 6 O2O line-of-sight marketing.

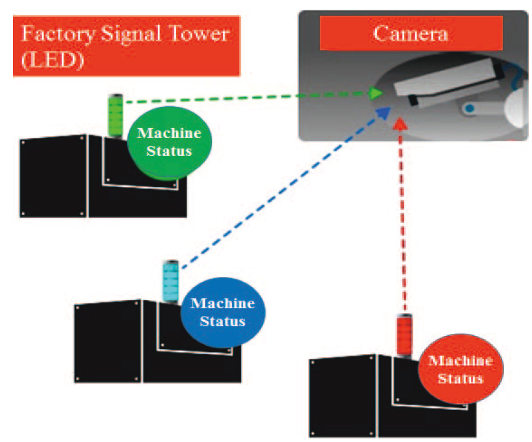

Fig. 7 Equipment monitoring.

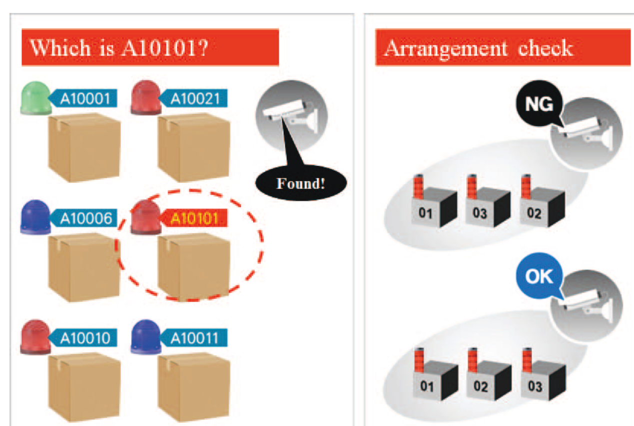

Fig. 8 Search and placement check.

The figure shows that the camera finds "Which machine has the ID number A10101?" and "Is the arrangement of those machines all right?".

6.3 Augmented Reality (AR) Using ISC

In vision-based AR, to overlap an object on an image, AR markers are used. For example, a two-dimensional code is often used as an AR marker. However, if the two-dimensional code is placed within 100 m from the camera, we would have to draw a huge two-dimensional code dozens

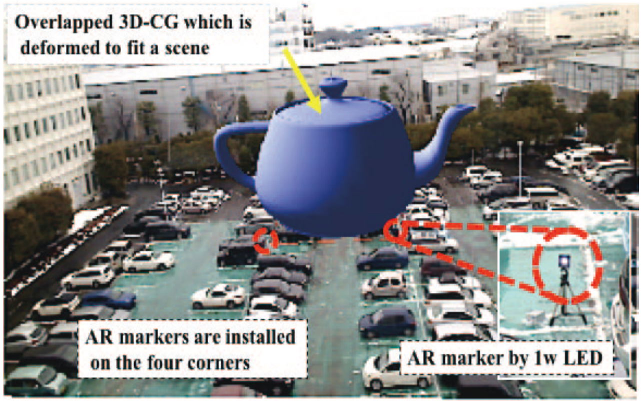

Fig. 9 ISC-AR markers.

of meters high.

In contrast, if we use blinking LED lights modulated by IDs as AR markers, very small ones are conspicuous even at long distances.

Figure 9 shows an experiment by CASIO in 2008, where four LED spot lights modulated by IDs are placed in a parking area to determine the direction of an AR model.

If the demodulation speed at an image sensor is sufficiently improved in the future, it would be possible to send not only ID data, but also CG-model data from an AR marker.

Long distance communication (such as 2 km) is possible at night between an LED lighthouse and a ship for a compact industrial camera. ISC can hide the data source in the LED light without changing its shape and provide variable ID and data.

6.4 Object Tracking with ID/Data

In safe and automatic driving, the internal state of a peripheral vehicle is as important as its precise XY position. The XY coordinates of the ISC signals on the scene image captured by the camera is provided. It is useful to be able to grasp the same positional relationships as the visual field of the driver's eyes.

Furthermore, it is possible to estimate the distance the signal in the Z direction according to the image size of the signal marker. This information can be obtained by integrating the results of the plurality of ISCs using secondary processing. The ISC system shown in [11], a system for obtaining world coordinate by combining XY coordinates by a plurality of cameras is shown.

As shown in Fig. 10, there are LED markers for the three forward cars on the highway sending "Steady driving," "CAUTION, panic braking," and "Accelerating" to the camera of the car behind them.

Confirming the precise positions and inner (driving) states of the forward three cars, the back car can determine its next driving state for safety or automatic driving.

Increasing numbers of drones will cause air traffic congestion in the future, as illustrated in Fig. 11. In this figure, there are four drones with LED markers that fly over the

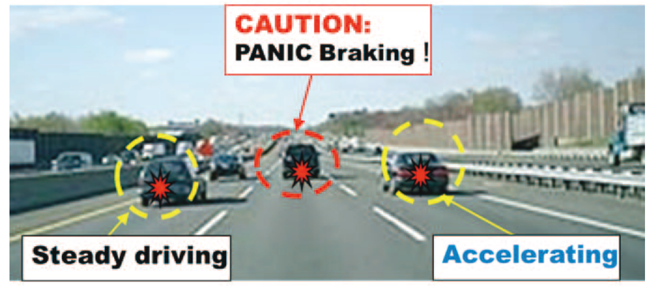

Fig. 10 High resolution automobile positioning and communication.

Fig. 11 Drones and LED beacon.

stadium, sending their ID data to the smartphone camera. Drones "Guard 02," "Media 01," "Media 09," and "Administrator 05" confirm their precise positions. The ID data and relation between their positions are convenient for air traffic controllers and remote controllers. This system is available even in indoor stadiums, tunnels, factories, underwater, and other environments where no GPS radio signals are received.

7. Conclusion

This paper reviewed the present status and future trends of ISC. In brief, ISC is a type of VLC that comprises modulated light objects (markers) and a camera with a lens and image sensor. The features of ISC, namely, multitarget tracking and reception, long distance transmission, and image acquisition as a by-product (very precise positioning of the objects) were discussed. In addition, LinkRay, FlowSign, Picalico and other prototypes were reviewed. Standardization for ISC and other VLC is currently underway in IEEE802.15.7r1 task group for ISC (OCC), and expected future ISC applications include O2O, IoT/M2M, AR, and object tracking with ID/data.

As described, the essential feature of ISC comes from its two-dimensional PD array structure. In other words, two-dimensional image coordinates are available, and this enables the precise positioning of an LED source. In this sense, the author believes that ISC will meet the essential requirements for connecting IoT things and information in the real world.

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Nobuo Iizuka obtained his bachelor's degree in Engineering from Gunma University in 1986. He is the General Manager of OIT Business Development Department, CASIO COMPUTER CO., LTD. Moreover, he is the member of board of trustees of Visible Light Communication Association.