VISIBLE LIGHT COMMUNICATION USING SUSTAINABLE LED LIGHTS

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ABSTRACT

LED lights are becoming widely used for homes and offices for their luminous efficacy improvement. Visible light communication (VLC) is a new way of wireless communication using visible light. Typical transmitters used for visible light communication are visible light LEDs and receivers are photodiodes and image sensors. We present new applications which will be made possible by visible light communication technology. Location-based services are considered to be especially suitable for visible light communication applications.

Keywords— visible light communication, led, image sensor, photo diode, location-based service

1. INTRODUCTION

White LEDs have recently been used as efficient light sources replacing incandescent light bulbs and fluorescent lamps. Figure 1 shows the luminous efficacy improvement curves for LED lamps and luminaires [1]. Currently the luminous efficacy of LED lamps and luminaires is around 100 lm/W (lumens per Watt), and expected to reach 200 lm/W around 2025, which is much higher than incandescent lamps (around 20 lm/W) and fluorescent lights (around 100 lm/W). LED lamps do not only have high luminous efficacy, but also long sustainability. LED lamps typically have a lifetime of 40,000 hours, which is 40 times longer than incandescent lamps.

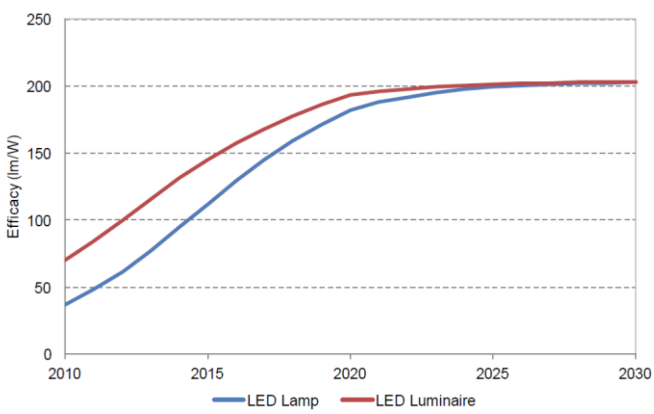

Figure 1. LED Luminous Efficacy Improvement

As the LED light technology improves, the price of LED light is falling rapidly as shown in Figure 2 [2]. The price of a 60 Watt LED light is expected to break US $10 in 2014 and US $5 in 2020.

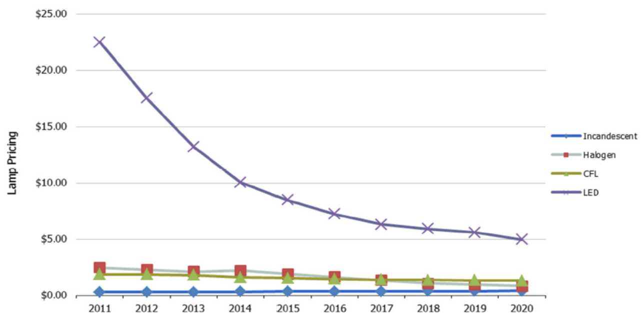

Figure 2. 60 Watt LED light price Trend

Thanks to the luminous efficacy improvement and long sustainability along with the lowering cost, LED lights are gaining a larger share every year. Its share will become 64 percent of the global lighting product market as shown in Figure 3 [3].

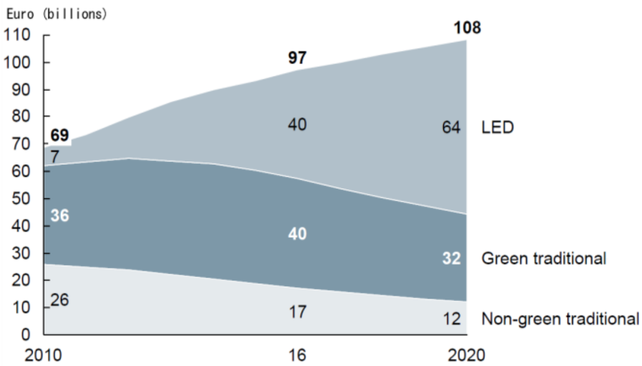

Figure 3. Global Lighting Product Market Trend in the World

("Green" is defined in line with typical energy efficiency standards, e.g., Energy Star for CFL lightbulbs.)

Governments in many countries are starting to ban inefficient lighting technologies such as incandescent lamps as shown in Figure 4 [3]. Countries such as USA, EU, Japan, China, Russia, and Brazil started to ban 100 Watt

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incandescent lamps by the end of 2012, and most will ban all incandescent lamps by 2016.

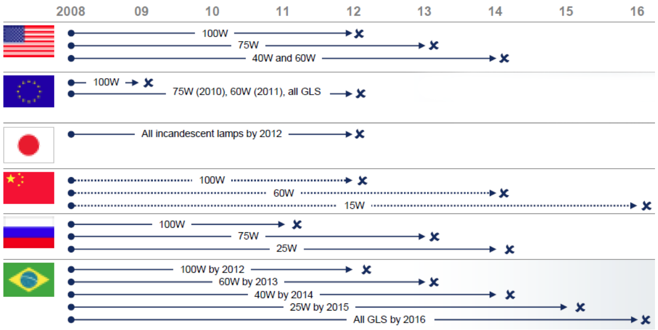

Figure 4. Incandescent Ban Plan in Residential Lighting in the World

Using increasingly popular LED lights, the visible light communication using LEDs is expected as a means for ubiquitous communication.

Visible light communication (VLC) has following advantages over other competing radio communication technologies such as WiFi and cellular phone wireless communication [4]: Visible light spectrum is available for communication because the frequency above 3THz is not currently regulated by the Radio Regulation Law. Visible light does not penetrate thick materials such as walls and partitions, which can be a security advantage. Visible light usually poses no health hazards to human body and eyes. Visible light also has following advantages over infrared communication technologies: Visible light can be literally visible so that human notices where the data is transmitted from. In addition, since LED lighting has recently become part of a building infrastructure, making visible light communication infrastructure is fairly easy by adding communication function to LED lighting.

Figure 5 shows a representative use of visible light communication, where an LED light is used as a data transmitter and a cellular phone with visible light sensor is used as a data receiver. The application of this system is indoor location service where a user uses a cellular phone with a photo diode, which detects signals from an LED light. This application is especially useful indoor because GPS receivers do not work well indoors even though they work well outdoors.

Figure 5. Visible Light Communication using LED Light: NEC, Matsushita Electric Works, Ltd, Keio University, CEATEC demonstration, Japan, 2004

The LED backlight of an LCD display can also be used as a data transmitter as shown in Figure 6. This is a visible light communication system made by NEC Corporation and Fuji Television in 2007, whose transmitter is an LED backlight of an LCD display and the receiver is a PIN photo diode attached to a PDA. While the regular image content is being displayed on the LCD screen, the LEDs in the backlight are turned on/off at a high speed to transmit text data. The transmitted data is received by a PDA device so that the text is displayed on the PDA. This system allows the transmission of information to hearing-impaired people or sight-impaired people.

Figure 6. Visible Light Communication to send Information using LED Backlight of LCD Display

The application of visible light communication using LED backlight panels as transmitter and PIN photo diode as receiver is shown in Figure 7. This prototype of digital signage was made by Visible Light Communications Consortium (VLCC) in Japan in September 2009. In this application, backlight LEDs send advertisement information, which is received by a user's terminal using a PIN photo diode. VLCC has been working with JEITA (Japan Electronics and Information Technology Industries Association) to define the standard of visible light ID system which can be used for applications such as location-based services and digital signage.

Figure 7. Visible Light Communication to send Advertisement Information using LED Backlight

When an LED light is used for illumination, its brightness has to be controlled. [5] discusses about the dimming control of LED lights as well as visible light communication for IEEE 802.15.7 standard, which was IEEE's first Wireless Personal Area Network (WPAN) standard for visible light communication. The IEEE 802.15.7 defines PHY and MAC layer for both bi-directional communication mode and broadcasting mode.

2. PROPERTIES OF VISIBLE LIGHT COMMUNICATION

Visible light communication has properties that are both advantageous and disadvantageous compared to radio-wave wireless communication. Its disadvantages are communication distance and data rate. The communication distance using visible light communication is typically between 1 to 100 meters. This distance is short compared to radio-wave communication, due to the fact that visible light communication is basically line-of-sight communication, which means that communication is interrupted when there is an object between a transmitter and a receiver. There is another disadvantage of visible light communication, which is data rate. Its data rate is typically between kilobits per second to 10 megabits per second, although there have been active researches going on to reach the speed of gigabits per second [6]. The bottle neck of the data rate is caused by the performance of either white LEDs or receiving photo sensors. The above disadvantageous properties of visible light communication may limit its use for many applications. However, these seemingly disadvantageous properties are indeed useful for some applications by taking advantage of line-of-sight property. We believe that those useful applications include location-based services and new graphical user interfaces that combine visual imagery with visible light communication. In this paper, we will explain some useful applications using the advantageous properties of visible light communication.

3. LOCATION-BASED SERVICES USING PHOTODIODE AS RECEIVER

We believe that the applications of visible light communication to location-based services and new graphical user interfaces that combine visual imagery with visible light communication have potential widespread use. For these applications, users are able to know the information associated with a transmitter. If a transmitter is attached to a building or a fixed place, location information will be obtained.

Indoor navigation is convenient for everyone, and it is especially indispensable for the visually impaired. We proposed such a navigation system for the visually impaired as shown in Figure 8 [7]. LED lights emit visible light with location data and a smartphone with a visible light receiver receives the data. The smartphone calculates the optimal path to a designation and speaks to the visually impaired through a headphone.

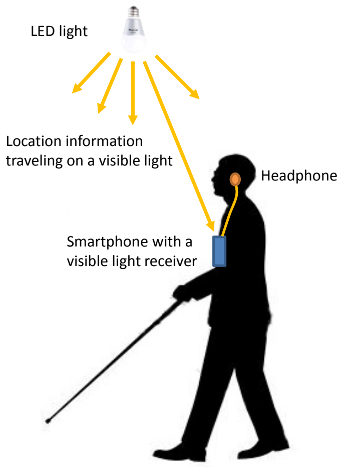

Figure 8. Indoor Navigation System for the Visually Impaired using Visible Light Communication

We made its navigation prototype and tested it for the visually impaired in 2012 as shown in Figure 9. We found that the prototype was able to navigate the visually impaired users fairly well with speech guidance.

Figure 9. Indoor Navigation Prototype for the Visually Impaired using Visible Light Communication

A prototype for a supermarket made by Nakagawa Laboratory in Tokyo is shown in Figure 10. An LED light sends location information and a shopping cart with a photodiode receives the location information.

LED Light sending location data

Shopping cart with photodiode near the wheels

Figure 10. Customer flow analysis system for a supermarket

The data of the path of a shopping cart can be recoded in a memory installed in the cart for one week with a battery. After all the data of all the carts are gathered, a statistical analysis is performed, and the example of the analysis is shown in Figure 11.

Figure 11. Example of customer flow analysis at a supermarket

The thick lines at a particular point in the supermarket indicate that many customers with carts walked through that point. Using this system, a supermarket manager is able to rearrange the goods to sell or improve the floor plan.

4. LOCATION-BASED SERVICES USING IMAGE SENSOR AS RECEIVER

Another interesting device that can be a receiver of visible light communication is an image sensor. An image sensor is able to do simultaneous image acquisition and data reception. Figure 12 shows the concept of visible light communication using image sensor as receiver. An image sensor continuously takes images of a scene with an LED light whose light intensity is modulated and a receiver detects the optical intensity at a pixel where the LED light is focused on.

Image sensors used for digital cameras or video cameras usually have frame rate of tens of frames per second. If a visible light signal from a visible light LED is received at a pixel of such an image sensor, the data rate is on the order of only several bits per second. However, using a high-speed image sensor whose frame rate is thousands of frames per second, it is possible to achieve data rate on the order of kilobits per second.

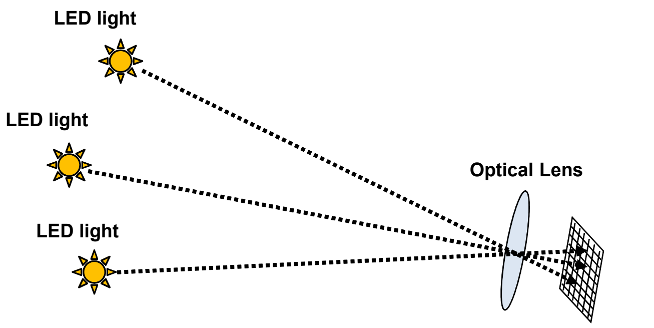

Figure 12. Concept of Visible Light Communication using Image Sensors as Receivers

The advantage of using an image sensor as receiver over a single photo diode is that even if there is a strong interfering light along with a desired signal, the interfering light will be focused onto a pixel which is different from a pixel onto which a desired signal is focused. This implies that image sensor reception is much more robust against interference than single photo diode reception.

A typical example of visible light communication using image sensors is shown in Figure 13 through 16. In Figure 13, a combination of digital camera and visible light communication is shown. LED transmitters are attached to users. The data associated with a user is sent from the LED transmitter and an image sensor detects not only its direction of a transmitter in an image, but also its received data contents. The monitor displays its contents at a location in an image where the data is sent from.

Figure 13. Application Example of Visible Light Communication using Image Sensors as Receivers

(Photo: Courtesy of Mr. N. Iizuka, Casio Computer Co., Ltd., Demonstration of Image Sensor Receiver, 2008)

Another application of visible light communication using image sensors is accurate position detection. Two examples of accurate position detection are shown: one in Figure 14 and the other in Figures 15 and 16.

In the first example in Figure 14, a photogrammetric method is used to detect the locations of LEDs attached to a water tank and the ground [8], [9]. The accuracy of position using photogrammetric method and visible light communication was about several millimeters at a distance of about 50 meters away from an image sensor. This accuracy of position is comparable to that of a typical surveying device called a total station. This system has another advantage over a total station, which is continuous monitoring of positions over time. The positions of LEDs attached to a water tank in Figure 14 were monitored for 24 hours. The roof of the water tank expands in the daytime and shrinks at night due to the heat from the sunshine. The visible light communication photogrammetric system was able to detect the position displacement of several millimeters with an accuracy of a millimeter at the distance of 40 meters.

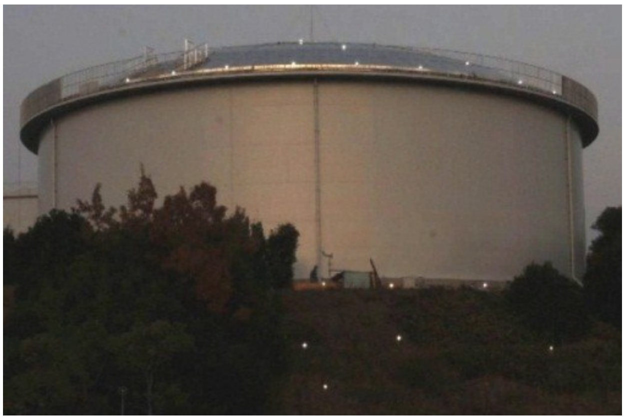

Figure 14. Survey Measurement using Image Sensors as Receivers

In the second example in Figures 15 and 16, a mobile robot detects its position by receiving location data from LED lights using two image sensors [10].

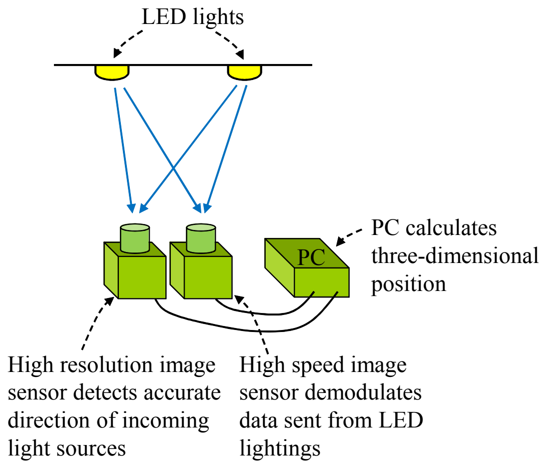

Figure 15. Robot Control System using Visible Light Communication

Figure 15 shows a robot control system using visible light communication. LED lights on the ceiling send location data. A robot has two image sensors: one image sensor obtains high-resolution image to detect an accurate direction of incoming light, and the other image sensor obtains high frame rate images in order to demodulate the incoming data on a visible light.

Figure 16. Robot Control Prototype with Centimeter Accuracy

We made a robot control prototype as shown in Figure 16 and found that a robot was able to detect its position with an accuracy of centimeter, which was good enough to control its motion.

5. CONCLUSION

We showed advantages and disadvantages of visible light communication and explained the effectiveness of location-based services for visible light communication by showing some examples. It is expected that visible light communication will be widely used as LED light market expands worldwide.

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