Visible Light Communication: An Innovative and Challenging Technology

Preecha Kocharoen, Petch Nantivatana, Kata Jaruwongrungsee, Termpong Srited, Wannaree Wongtrairat and Piya Kovintavewat

ABSTRACT

Since the Internet of Things (IoT) allow devices to be interconnected across communication networks, the demand for bandwidth in personal communication is growing rapidly as the number of devices increases. Moreover, the location estimation in an indoor environment requires a proper technology because the global positioning system cannot provide satisfactory accuracy. Thus, a visible light communication (VLC) technology is introduced so as to add extra capacity to an existing radio frequency infrastructure. In practice, the VLC can utilize the lighting system infrastructure to transmit data via light intensity together with illumination. Several VLC standards have been published by the Japan Electronics and Information Technology Industries Association (JEITA) and the institute of electrical and electronics engineers (IEEE) in 2003 and 2011, respectively. In the past five years, many researchers in Thailand have focused on both VLC basic research and technology implementation. Additionally, the inter-University co-operation known as LED-SmartCon has also been established by ECTI Association to promote the VLC technology in Thailand. Moreover, the VLC development kit was developed by SARGMET researchers, according to the CP1223 standard definition. This helps reduce the time to develop the VLC products with the ease of use and low complexity.

Keywords

Visible Light Communication, Communication Standard, Thai Preparations

I. INTRODUCTION

Since the demand for bandwidths in personal communication, i.e., mobile phone, computer, wearable device, and Internet of Things, is growing rapidly as the number of users increases, an alternative communication technology is required to add extra capacity to an existing radio frequency infrastructure. Radio frequency communication has some limitation when people carry more than one communication device at the same time, because each device needs high data rates. Furthermore, a location-specific service has recently received more attention because the global positioning system (GPS) cannot provide satisfactory accuracy for estimating the location in both indoor and outdoor environments. Examples for indoor and outdoor environment services are location-specific multimedia contents, security messages, illuminated advertising boards, car-to-car communication, intelligent transportation systems (ITS), and so forth.

Visible light communication (VLC) is an emerging technology that is being researched to use light emitting diode (LED) as a transmitting light source for communication systems. Unlike radio frequency systems, VLC can be used in hospitals, under water communication and electromagnetic interference sensible locations. Applications such as VLC for audio systems and information broadcasting using traffic lights are examples of the capabilities of VLC. This optical communication could be used for addressing the congested spectrum bandwidth of radio frequency communication. This wireless communication carries information by modulating the light with wavelength of about 400 – 700 nm, which is in the visible light spectrum band. The VLC system can utilize the existing lighting system infrastructure to transmit data along with illumination, which can be achieved by sending data via light intensity. There are two common approaches to produce LED white light illumination, namely the blue LED with a phosphor, and the combination of red, green, and blue (RGB) LEDS. However, if a high transmission rate is required, the RGB method is preferred because the phosphor has a slow response and then the bandwidth is limited. Moreover, the RGB LEDs could be transmitted simultaneously by using a wavelength division multiplexing (WDM) technique, which could increase the transmission rate.

Now the light we use in our daily life is employed not only for providing light, but also for communication; however, many technical issues might need to be addressed. For visible light communication, two standards were published by the visible light communication consortium (VLCC) [1] and the institute of electrical and electronics engineers (IEEE) [2] in 2003 and 2011, respectively.

II. VLC System

Generally, VLC utilizes LEDs to transmit data by turning on and turning off the light at a speed undetectable by human eyes. At the receiver, the photodiode will convert the optical signal to the electrical signal, and then the modulating signal will be retrieved. A typical indoor VLC system is illustrated in Figure 1. The LED lamps are installed on the ceiling for illuminating all areas in a building, including rooms and corridors. One of the lamps is functioned as a coordinator to transmit visible light beacon or data frame, e.g., computer data, serial number, product information, or location information, through all LED lamps. Thus, the receiver or the VLC end device can obtain information from the coordinator device via light intensity. The information may include additional data, e.g., product name, product specification, or the location where the lamp is installed. The up-link from a VLC end device to a coordinator device could be on a modulated retro reflector [3], transmitting VLC in the dark [4], or existing RF or IrDA link. A modulated retro reflector controls the amplitude of the incident light from the LED transmitter before reflecting back to the coordinator. In the case of VLC in the dark, the duty cycle of the LED light is reduced so as to produce a very narrow pulse width such that the lamp appears dark, while the receiver in the coordinator device can still detect the transmitted signal.

"Unlike radio frequency systems, VLC can be used in hospitals, under water communication and electromagnetic interference sensible locations."

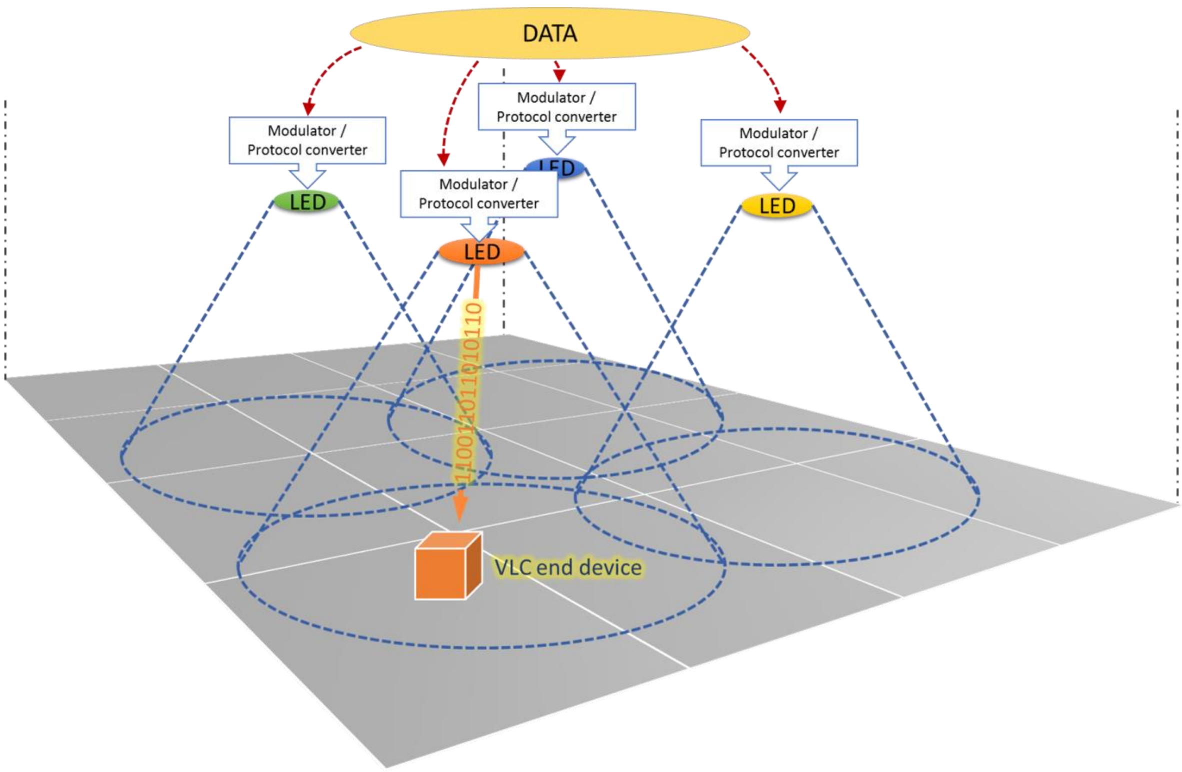


Figure 1: An example of an indoor VLC system.

In addition, Figure 2 shows an outdoor VLC system, which can provide connectivity between car and road infrastructure, e.g., car's head light and rear light, traffic light, or illuminated advertising board so as to exchange information among all devices in the intelligent transport systems.

Applications on VLC can be classified based on indoor/outdoor applications or low/high bit rate. An example of an indoor/low bit rate group is the infrastructure with fixed lamp location to enable identification broadcasting or location information, whereas that of an indoor/high bit rate group is data communication via a mobile device, which uses battery as a power supply; therefore, it can transmit data only for a short distance. On the other hand, an example of outdoor/low bit rate group is a car-to-car communication or car-to-road infrastructure communication that has a moderate power supply and intense light source for using long range communication, while that of an outdoor/high bit rate group is a communication between two network stations using a very intense light source with fixed coordinator. Examples of VLC potential applications are included:

1) Indoor data communication that uses light from LEDs as a medium to deliver high-speed communication.
2) Low-cost indoor navigation that uses existing ceiling lamps to broadcast location IDs that the mobile receiver unit can be used to calculate the current location.
3) Location based services that use the existing lighting infrastructure to deliver personalized content based on location e.g. pushing the digital content to shoppers in the stores or personalized content delivery in the museums or galleries.
4) Visible light barcodes broadcasted from billboards or advertising boards.
5) Intelligent transportation systems that could be used for vehicular communications, e.g., vehicle to infrastructure, vehicle to vehicle, or infrastructure to vehicle.
6) VLC can be used as smart lighting from public lighting, i.e., street lamps. The lamps could be used to provide communication hotspots or could be used to monitor or controlling some devices.

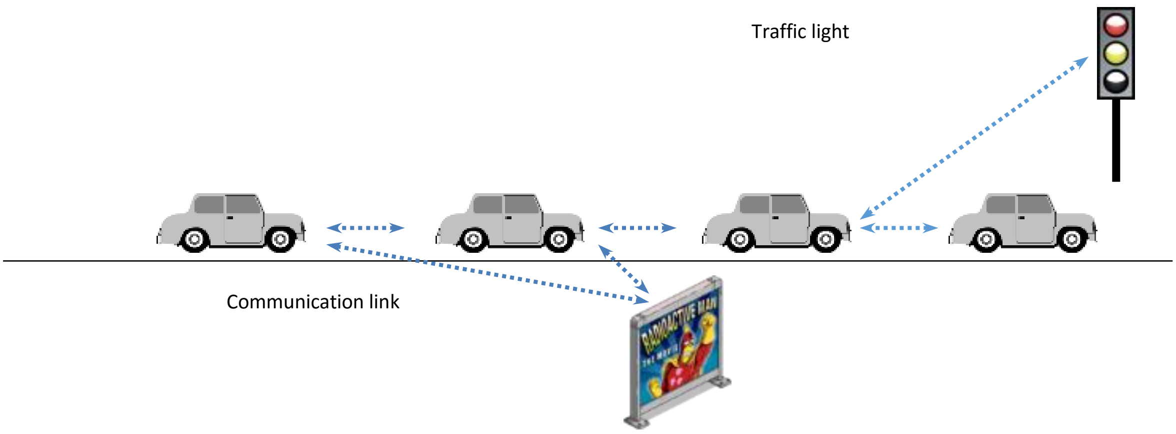


Figure 2: An example of an outdoor VLC system.

7) VLC can provide a robust communication comparable to radio frequency communication in the hazardous environments such as mines or industrial plants.
8) VLC does not interfere with medical instruments such as MRI scanners or aircraft radio communications; therefore, it could be used in the hospital or airplanes.
9) VLC could be used in underwater communications where radio frequency communication could not be used because of extremely high RF and acoustic wave signal distortion.

III. VLC Standard

There are several standards related to VLC, but only two potential standards are described in this paper, namely IEEE 802.15.7 and CP1223. The institute of electrical and electronics engineers defined a standard, called IEEE 802.15.7, for short-range optical wireless communication using visible light. This standard defines only two layers, physical layer (PHY) and medium access control layer (MAC), in OSI 7-layers model [2]. The PHY layer is responsible for controlling light transceiver along with signal-level control mechanism. Three types of PHY layer are supported, which are different in spectrum frequency band, data rate and optical clock rate. The PHY I is intended for outdoor use with low data rate applications. This mode can support a data rate up to 266.6 kbps. The PHY II is intended for indoor use with moderate data rate applications. It uses on-off keying or variable pulse position modulation as a modulation scheme with higher optical rate up to 120 MHz. This mode can support data rate up to 96 Mbps. The last mode, PHY III, is intended for application using multiple light sources and detector that can gain advantage from band-hopping to avoid interference. The PHY III uses color-shift keying (CSK) as a modulation scheme with optical rate up to 24 MHz. This mode can support data rate up to 96 Mbps.

The MAC layer handles all accesses to the PHY layer using superframe structure. The superframe composes of several slots, including active period, beacon, contention access period (CAP) or Contention free period (CFP), and inactive period. The beacons are used to synchronize end devices to the coordinator device. When any end device wants to communicate with the coordinator, it might have to compete with other devices via random access during a contention access period. On the other hand, for the end device that requires specific data bandwidth, the dedicate portions, called guaranteed time slots (GTSs), are assigned by a coordinator device during a contention free period.

> *"The VLC system can utilize the existing lighting system infrastructure to transmit data along with illumination, which can be achieved by sending data via light intensity."*

The other standard called CP1223 was issued by the Japan Electronics and Information Technology Industries Association (JEITA), Japan. This standard prescribes the unidirectional communication system with visible light as a medium for multimedia applications. The visible light beacon transmitter can transmit information either arbitrary data or an ID code. Optical wavelengths of this standard are around 380 – 780 nm with data rate of about 4.8 kbps. The modulation techniques used in this system is inverted 4 pulse position modulation (I-4PPM). The transmission frame structure consists of a preamble (PRE), frame-type (F-TYPE), payload and cyclic redundancy check (CRC-16). The payload may contain ID information and/or 128-bits data. This standard can be applied for various multimedia applications, such as the transmission of advertisements or the security information from illuminated advertising board, emergency exit signs, where Content ID is sent from an LED light and various location-dependent contents directly from the light.

IV. RECENT RESEARCHES IN THAILAND

In the past five years, many researchers in Thailand have focused on the VLC technology. For example, researchers at the faculty of engineering, Chulalongkorn University and the national electronics and computer technology center (NECTEC) presented channel modeling of visible light communication [5]. Moreover, they proposed an indoor positioning system for LEDs based on received signal strength and fingerprinting in order to estimate the position of the receiver [6]. On the other hand, at the industrial robot research and development center, King Mongkut's University of Technology North Bangkok, researchers have proposed an indoor positioning system for robot localization. They proposed an integrated angle of arrival-received signal strength (AOA-RSS) localization method using the VLC. It has been implemented to achieve high accuracy for robot localization with a small error approximation of a few centimeters [7].

The alternative technique for location estimation using spread spectrum has been proposed by researchers from the faculty of engineering, Sripatum University. This technique embeds the Gold sequence to LED lamp, which can distinguish from other sequences by using the correlator [8]. The study on handover in visible light communication was reported by researchers at the faculty of engineering, Naresuan University [9]. In addition, Researchers at the Bangkok University center of research in optoelectronics, communications and control systems (BU-CROCCS), school of engineering, Bangkok University has concentrated mainly on low cost transceiver design supporting both digital and analogue intensity modulation formats. The transceiver has been designed to support VLC over dimmable light. A software defined approach has been used for the implementations of the modulation and coding schemes to improve the quality of VLC communication links. They also present an application of software defined communication systems to transmit location information of displaying item in a smart museum [10]. Application of LED for health has been focused by researchers at Rajamangala University of Technology Isan and demonstrated at the 7th Rajamangala University of technology conference [11].

To accelerate the VLC technology development in Thailand, both fundamental research and technology implementation have to be developed at the same time. The VLC development kit that in compliance with CP1223 standard has been developed by inter-University co-operation, Sripatum University, Nakhon Pathom Rajabhat University, Rajamangala University of technology Isan, King Mongkut's University of technology north Bangkok and NECTEC, in order to accelerate the product time to market for industrial partners. Not only the inter-University co-operation has been set up, but also Thai VLC consortium, called LED-SmartCon, has been established by ECTI Association.

The LED-SmartCon aims to promote the LED for communications, industrial applications, and health, among researchers, students, and industrial partners. One of LED-SmartCon activity is to promote VLC by arranging a meeting for researchers, students, and industrial partners from all around Thailand. The website and social media are also set up for LED-SmartCon, which can be found at http://led-smartcon.org/, https://www.facebook.com/Visible LightThailand, and http://dept.npru.ac.th/vlc.

V. VLC Development Kits

To accelerate the VLC technology development, the guideline of development platform both hardware and software are needed. Therefore, the VLC development kit in compliance with the CP1223 standard has been developed in order to accelerate the production time to market for industrial partners. The development kit consists of two parts, namely the hardware and the software. In the hardware design, the ease of use and cost of building or development work have been taken into account. The ease of use has made the selection of Arduino microcontroller in order to start the development of optical communication products quickly and easily. The selected Arduino microcontroller model used in this design is Arduino Pro micro (mini Leonardo), which is popular among developers and it is small and affordable. This Arduino Pro micro is employed to control the operation of electronic hardware. In the software or programming part, the structure of the program is made clear and easy to edit. Moreover, we are also preparing all source codes so as to demonstrate a large number of applications.

The wireless optical development kits consist of a wireless transmitter and receiver kits as shown in Figure 3. Both devices have the same hardware that can be configured to be a transmitter or a receiver module. Each development board equipped with a main board, a microcontroller Arduino Pro micro (mini Leonardo), and the extensions that are supported input and output as illustrated in Figure 4.

The block diagram of the development board is also given in Figure 5. The processing equipment and a controlling device utilize the Arduino Pro microcontroller that has to be programmed differently. For the transmitter board, the information signal generated from the microcontroller is fed to a transmitting circuit that is connected to the LED light source device. The information is transmitted via the illumination of the emitted light by the LED driver circuit on the development board.

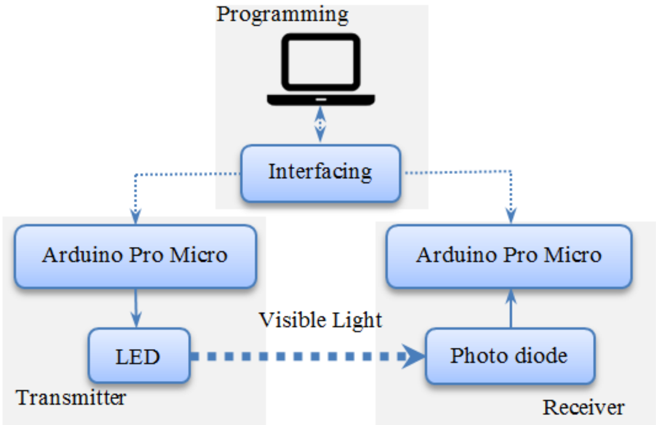


Figure 3: System overview.

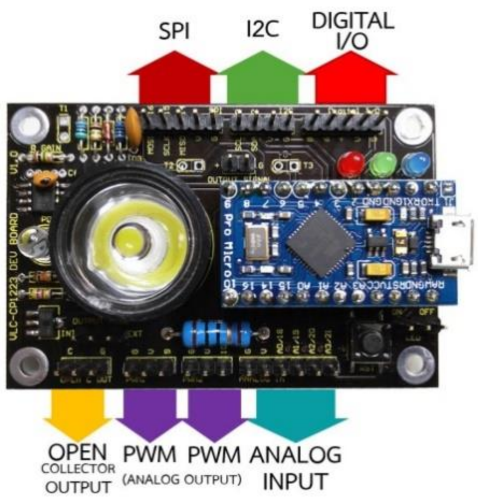


Figure 4: A development board.

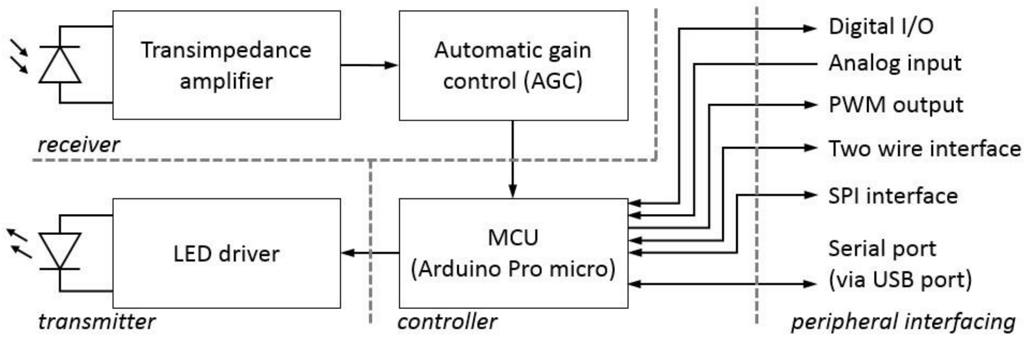
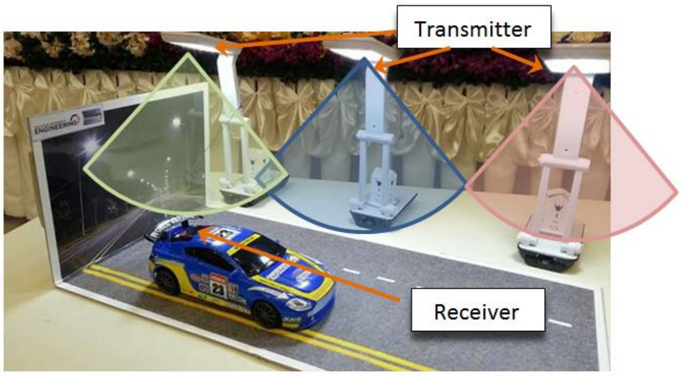


Figure 5: Block diagram of the development board.

At the receiver, the signal is retrieved by using a photo diode with an amplifier and then passes through the microcontroller, which is programmed to decode the transmitted sequences. The operation of the control system for this wireless optical communication can be done by microcontroller software programming through a computer via an interface board. To control the microcontroller Arduino Pro micro (mini Leonardo), the Arduino IDE program is used. This Arduino IDE program is an open source that is developed for programming and uploads the program sketch to the microcontroller device. The Arduino IDE can be downloaded at https://www.arduino.cc/en/Main/Software. The microcontroller programs are developed by the two major parts, namely the main program and the function library. Generally, the main program is used to control the development board, including commands to control variables, registers and ports, and command sequence control functions to control the program procedure. Moreover, the program that controls the basic level, which is called the function library, VLC_CP1223_QSC.h, is written separately from the main program and will be run when needed. This function library is written to declare addressing, the list of critical functions, constants and variables of the transmitter and the receiver.

Examples of implementation by using VLC Development Kits are shown in Figure 6 to Figure 9. Figure 6 demonstrates three different visible light data from three street light models. The photo diode receiver is installed on the car model when the signal from the street light model above the car, the VLC signal is demodulated and decoded. After moving the car to the other street light, the different information from the next transmitter is then obtained. Therefore, this can be used to broadcast information by using street light. Figure 7 demonstrates the vehicle gate control application. The VLC system is installed on the car model that can transmit the gate-open code from the car front light. When the car is closed to the gate, the receiver will receive the gate-open code from the front light. If the gate-open code is correct, then the gate will be opened. Moreover, the smart museum application is displayed in Figure 8. The VLC system is installed in the flood light to broadcast the object's identity. When the VLC receiver receives the data from the floodlight, the receiver will demodulated and decoded to get the information and command the audio player module to play the audio file on the memory card. This can be used in the smart museum that each flood light can represent the object's identities and the visitor who want to get the information of the displayed object only need to take the receiver be shined under the object's flood light. Finally, the signal of both transmitter and receiver of the VLC development kits is measured and shown in Figure 9.


Transmitter
Receiver

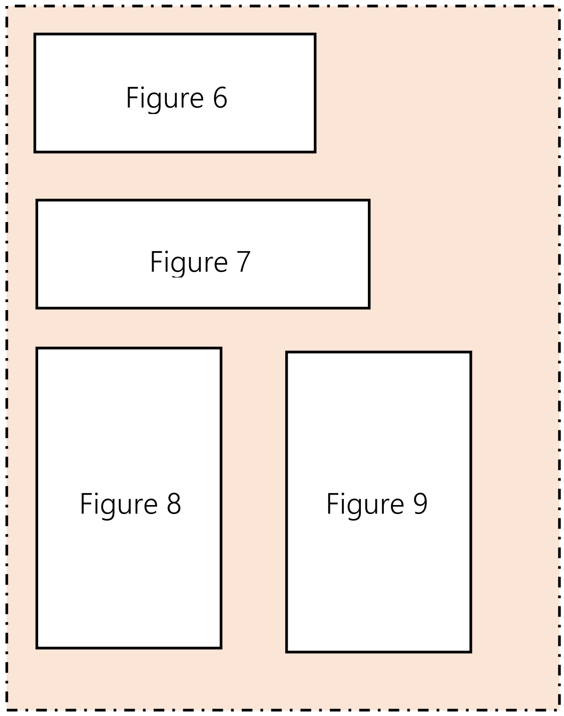
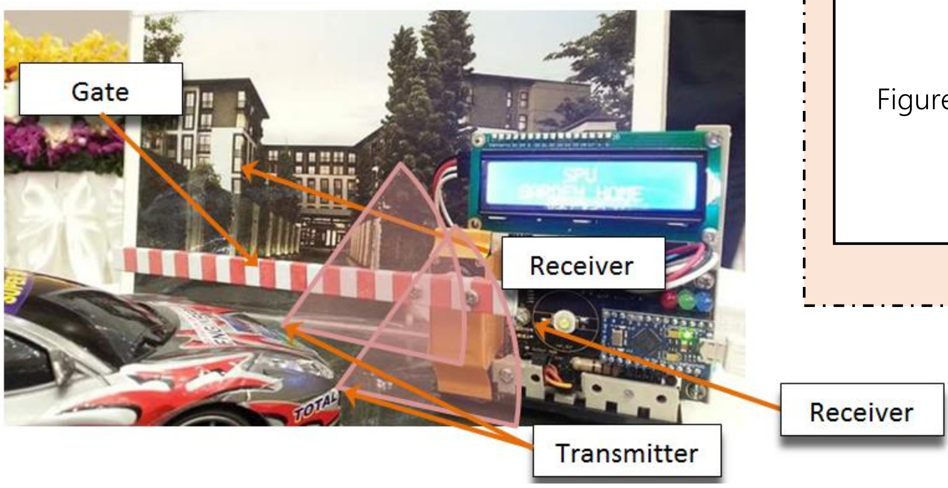
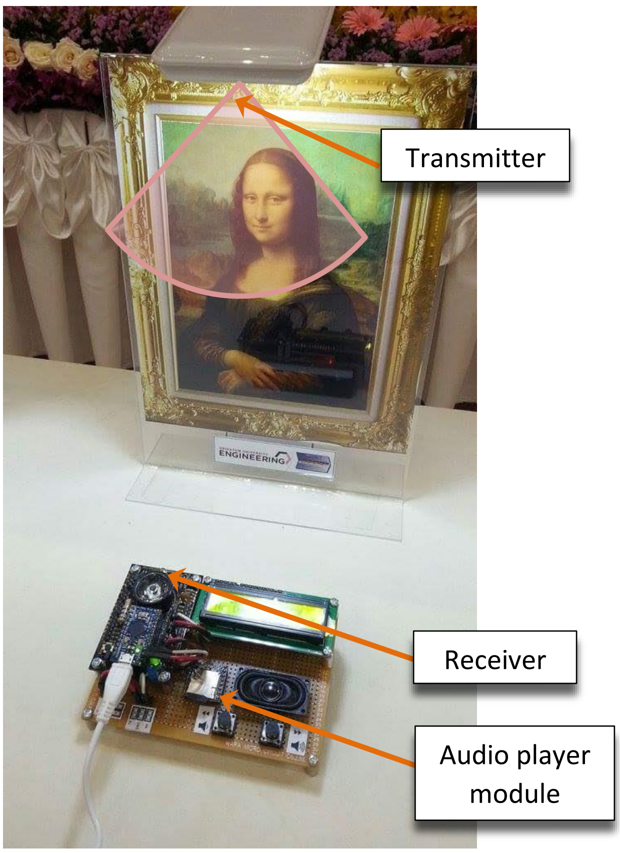
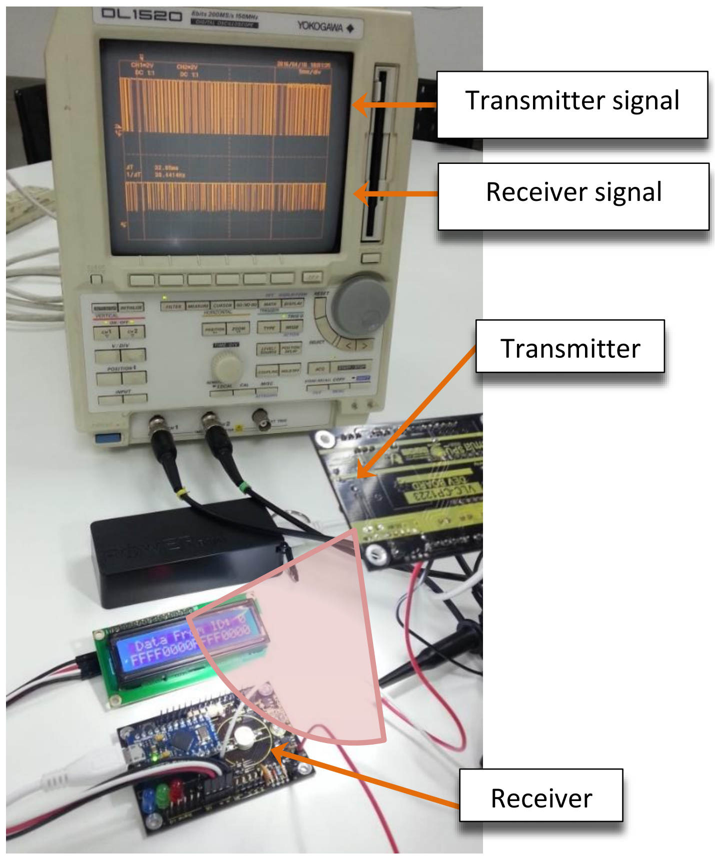


Figure 6
Figure 7
Figure 8
Figure 9


Gate
Receiver
Receiver
Transmitter


Transmitter
Receiver
Audio player
module


Transmitter signal
Receiver signal
Transmitter
Receiver

VI. CONCLUSIONS

As we rapidly run out of radio spectrum, VLC could be an alternative technology to support the Internet of Things age. Applications on VLC can be classified into four groups based on indoor/outdoor with low/high bitrate. For indoor, the VLC could use the existing infrastructure of the lighting system to transmit visible light beacon or data frame along with illumination. For outdoor, VLC can be used in the intelligent transportation systems by providing communication between car to car and car to road infrastructure. Currently, Thai VLC consortium, namely LED-SmartCon, has been established by ECTI Association to accelerate both VLC fundamental research and technology implementation in Thailand. The LED-SmartCon aims to promote the LED for communications, industrial applications, and health, among researchers, students, and industrial partners. Furthermore, the VLC development kit has been developed by SARGMET researchers, which could be used to expedite the production time to market for industrial partners. The guideline of development platform both hardware and software for CP1223 standard has been introduced to accelerate the development of VLC technology in Thailand.

VII. ACKNOWLEDGEMENTS

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BIOGRAPHY

Associate Professor Dr. Preecha Kocharoen has been working as a lecturer with the Sripatum University since 1999. He graduated in B.Eng. (Electrical), M.Eng (Communications), and D.Eng (Telecommunications) in 1997, 1998, and 2006 respectively. He received best faculty award for young researcher and best faculty award in academic in 2009 and 2013 respectively. He has been serving to several professional organizations for many years including Thai Embedded System Association (TESA) and IEEE ComSoc (Thailand). He is currently an IEEE senior member and ECTI member.

Petch Nantivatana has been working as a lecturer with the Sripatum University. He graduated in B.Eng. (Electrical) from Sripatum University and M.Eng (Electronics) from King Mongkut's Institute of Technology Ladkrabang (KMITL), in 2000 and 2005 respectively. His current research interests include microwave ablation, signal and image processing, embedded system, wireless sensor network and visible light communication.

Kata Jaruwongrungsee received his B.Eng. (electronics), M.Eng. (electronics) and D.Eng. (Electrical) from King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand, in 2003, 2005, and 2015 respectively. He has been working as a Researcher in Nanoelectronics and MEMS Laboratory, National Electronics and Computer Technology Center (NECTEC), Thailand, since 2006. His research is mainly focused on chemical and biological sensing technology.

Termpong Srited has been working as a lecturer with the Sripatum University since 2001. He graduated in B.Eng. (Electrical) in 1998. His current research interests include embedded system, wireless sensor network and visible light communication.

Assistant Professor Dr. Wannaree Wongtrairat was born in Nakhonratchasima, Thailand. She received the B.Eng. and M.Eng. degrees in telecommunications engineering in 2000 and 2003, respectively, and D.Eng. degree in Electrical Engineering in 2009 from King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand. She is a lecturer at the Department of Electronics Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhonratchasima. Her research interests wireless communications, digital signal processing, and electronic application device for agricultures.

Associate Professor Dr.Piya Kovintavewat received the B.Eng. summa cum laude from Thammasat University, Thailand (1994), the M.S. degree from Chalmers University of Technology, Sweden (1998), and the Ph.D. degree from Georgia Institute of Technology (2004), all in Electrical Engineering. He currently works at Nakhon Pathom Rajabhat University. His research interests include coding and signal processing as applied to digital data storage systems. Prior to working at NPRU, he worked as a research assistant at National Electronics and Computer Technology Center (1999), both in Thailand. He also had work experiences with Seagate Technology, Pennsylvania, USA (summers 2001, 2002, and 2004).