

Visible Light Identification System for Smart Door Lock Application with Small Area Outdoor Interface

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Visible light identification (VLID) is a user identification system for a door lock application using smartphone that adopts visible light communication (VLC) technology with the objective of high security, small form factor, and cost effectiveness. The user is verified by the identification application program of a smartphone via fingerprint recognition or password entry. If the authentication succeeds, the corresponding encoded visible light signals are transmitted by a light emitting diode (LED) camera flash. Then, only a small size and low cost photodiode as an outdoor interface converts the light signal to the digital data along with a comparator, and runs the authentication process, and releases the lock. VLID can utilize powerful state-of-the-art hardware and software of smartphones. Furthermore, the door lock system is allowed to be easily upgraded with advanced technologies without its modification and replacement. It can be upgraded by just update the software of smartphone application or replacing the smartphone with the latest one. Additionally, wireless connection between a smartphone and a smart home hub is established automatically via Bluetooth for updating the password and controlling the home devices. In this paper, we demonstrate a prototype VLID door lock system that is built up with LEGO blocks, a photodiode, a comparator circuit, Bluetooth module, and FPGA board.

Keywords : Visible light identification, Door lock, Smartphone, Security

OCIS codes : (060.4510) Optical communication; (060.4785) Optical security and encryption

I. INTRODUCTION

Currently, electronic door lock systems have been widely deployed in houses and offices since the operation without keys enhances convenience as well as security. By and large, keypads that consist of physical buttons or touch panels are embodied as an outdoor interface with users. However, such physical buttons and touch panels require the large area as well as the high cost to implement. Recently, a near field communication (NFC) door lock system [1] has been proposed to cope with area and cost issues. The door lock system is controlled through the NFC technology by simply clicking a smartphone button. Although the area of an outdoor interface can be substantially reduced compared to keypads, NFC receivers need some specific area for the antenna that is larger than 15 cm² [2].

In this paper, we propose a new visible light identification (VLID) door lock system that uses the visible light from a light emitting diode (LED) camera flash integrated in the backside of a smartphone to transfer the user information. The visible-light-based communication has been in the spotlight in the fields of indoor hospital communication systems, indoor navigation systems, intelligent transportation systems, and machine-to-machine communication systems [3-7]. The visible light is safer than any other wireless communication technologies regarding the security issue due to its line-of-sight propagation that cannot penetrate walls [8-9]. Furthermore, unlike radio frequency communications, its good visibility enables users just with the naked eyes to ascertain easily the data transmission. Without any inconvenient processes, the pairing between transmitter and receiver is established only by placing them face-to-face on the line-of-sight path.

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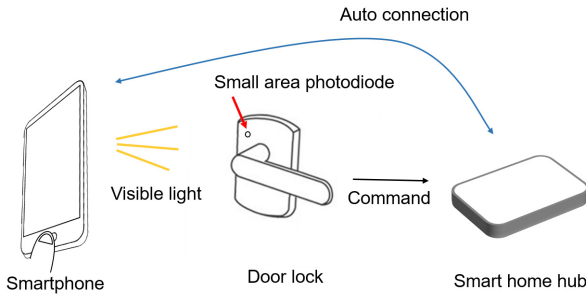


FIG. 1. Proposed VLID door lock system.

A proposed VLID door lock system can take advantage of powerful and convenient security methods of smartphones that have evolved rapidly with latest cutting-edge technologies. Whereas, the receiver can be simply implemented at low cost with a photodiode, a comparator circuit, and a simple processor. Especially, the outdoor interface is simplified with the significantly small area for only a photodiode, compared to other previous approaches. Additionally, the proposed VLID system provides a user with the automatic wireless connection to a smart home system [10] to control smart home devices such as lightings, curtains, gas valve and sockets. Furthermore, this wireless network helps to achieve the high security by updating the password every single success of connection.

This paper demonstrates a prototype VLID door lock system as shown in Fig. 1 with an Android based smartphone, a photodiode, LEGO blocks, a field programmable gate array (FPGA) board, and simple comparator circuits. A Bluetooth module is attached to the FPGA board in order to realize a smart home hub.

II. VISIBLE LIGHT IDENTIFICATION (VLID)

2.1. Overall Operation of VLID Door Lock System

As a first step, a user should register a smartphone to a VLID door lock system. Like conventional systems, a new phone can be registered only when a door is opened. After the indoor part of a door lock enters the registration mode by pressing a button, the new password randomly generated by a smart phone is transferred through an outdoor photodiode.

In normal operation, a user places the back-side of a smartphone on a door lock to contact a camera flash to a photodiode. Consequently, a user can access the smartphone's VLID application program without any inconvenience during the door lock operation because the smartphone's screen turns toward the user.

Figure 2 shows a block diagram of the proposed VLID system. When a user enters a password or puts a finger on a fingerprint sensor of a smartphone, an internal powerful processor identifies the user and generates the corresponding binary passcode for visible light transmission.

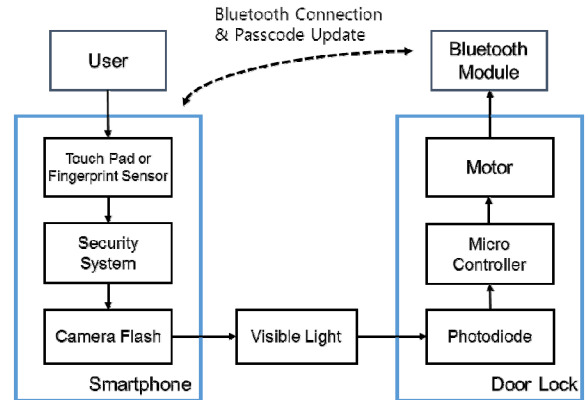


FIG. 2. Block diagram of VLID door lock system.

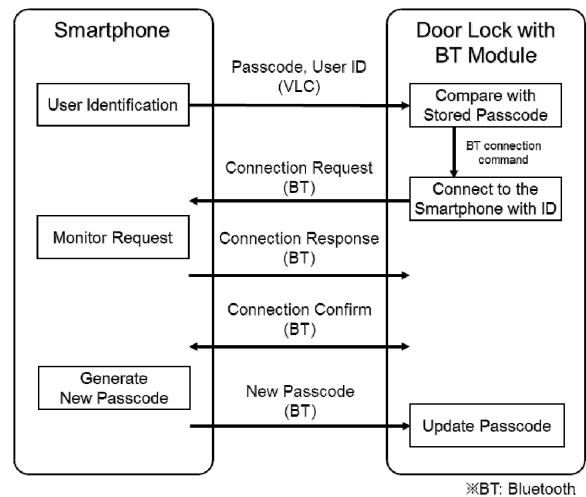


FIG. 3. Procedure of VLID door lock operation.

Then, the generated code is converted into visible light through a camera flash of a smartphone. The receiver of a VLID door lock senses the flash light sequence that is recovered into the binary stream. When the received binary data are equal to the binary passcode stored in advance, the processor of the door lock operates a servo motor and a Bluetooth module to open a door and to establish the connection with the smartphone, respectively. After the Bluetooth link is established, the new passcode randomly made up by a smartphone is updated at both smartphone and door lock system leading to strong security. Because the passcode is changed every VLID operation, anybody can not figure out the password by stealing a glance of a flickering LED.

A detailed process of the proposed VLID system is illustrated in Fig. 3. After the smartphone identifies a user, it transmits the binary VLC signal consisted of a passcode and a user ID to a door lock receiver. And then, the door lock compares the received passcode with the passcode that is stored in advance and commands a Bluetooth module to send a connection request to the smartphone

with the received user ID. The smartphone keeps monitoring a connection request and sends a connection response to the door lock when the corresponding request is received. The connection is established by the smartphone and the door lock exchanging the connection confirm signal. Then, the smartphone generates the new random passcode that is shared with the door lock via Bluetooth.

2.2. VLID Transmitter and Receiver

When a VLID application program of a smartphone that is a VLID transmitter verifies the user through a personal identification number (PIN) code, alphabets, or fingerprint, the binary code of 72-bit length is generated with 4-bit start code, 64-bit passcode, and 4-bit device ID number. The passcode should be shared between the smartphone and door lock system in advance, and it is updated at every operation. The device ID number assigned by the door lock system when registering the smartphone allows a receiver to be able to identify each user. Then, the program turns on and off a camera flash by means of on-off keying (OOK) modulation [11] according to the generated binary sequence.

A VLID receiver is implemented in a door lock system in order to convert the visible light input into the digital data of electrical signal and process user identification and door lock control. Especially, as VLID transmitter and receiver systems are separated without any shared signals except for the line-of-sight light link, operating clocks at transmitter and receiver sides suffer from inevitable frequency and phase mismatches that cause serious communication errors. The proposed VLID receiver employs a simple clock data recovery (CDR) to compensate for these mismatches. It has been reported that the simple CDR adjusts the sampling instant with a triple sampling scheme at a fixed clock signal without any complicated phase locked loop (PLL) circuit [12]. A triple sampling provides three samples per one received binary symbol as illustrated in Fig. 4. An output symbol is decided to be equal to the level of majority samples and the timing adjustment takes place when there are only two consecutive equal samples with a remaining sample of the different level. UP reduces the sampling interval and DOWN increases the sampling interval to compensate for frequency and phase mismatches. It has been verified that this scheme is valid within $\pm 1.5\%$ mismatch range of transmitter and receiver operating frequencies.

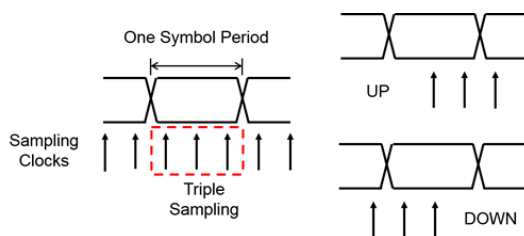


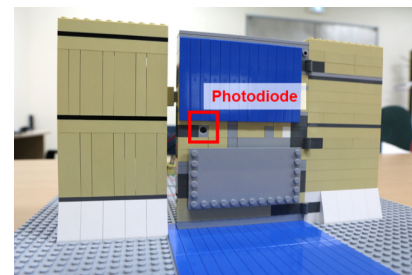
FIG. 4. Triple sampling and UP/DOWN condition for frequency offset compensation.

III. PROTOTYPE DESIGN & EVALUATION

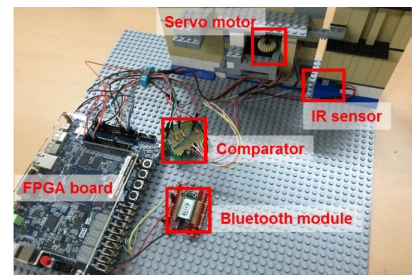
A prototype door lock system is designed with LEGO blocks, a servo motor, and a VLID receiver that is composed of a photodiode, a comparator, and FPGA board, as presented in Figs. 5 (a) and (b). In addition, an infrared (IR) sensor circuit is supplemented to lock automatically the door when closed and a Bluetooth module is attached to the FPGA board to realize a smart home hub and to update a password every VLID operation.

The application program of a VLID transmitter is implemented on an Android operating system with Samsung Galaxy S6. One among any passwords that are the combination of numbers and alphabets and the fingerprint can be used for authentication as shown in Fig. 6(a). As soon as the Bluetooth connection is established, the smart home control page automatically appears on a screen of the smart phone as shown in Fig. 6(b). Then, the user can control the smart home devices such as LED lightings and audio system with the smartphone application. The flashing frequency is set to be around 40 Hz that leads to the operation time of around 2 seconds and the output waveform of the comparator at the VLID receiver is presented in Fig. 7.

The procedure of a prototype VLID door lock operation is explained in Figs. 8 (a) to (e). First, the smartphone identifies the user with password or fingerprint. Second, after the password or fingerprint is confirmed, the visible light is transmitted through a camera flash according to the generated code. Third, when the received data is verified, the door lock is released and the door opens automatically. Fourth, the After Bluetooth connection between the door lock system and the smartphone is established, the pass-



(a)



(b)

FIG. 5. Photograph of prototype VLID door lock system: (a) Front side; (b) Back side.

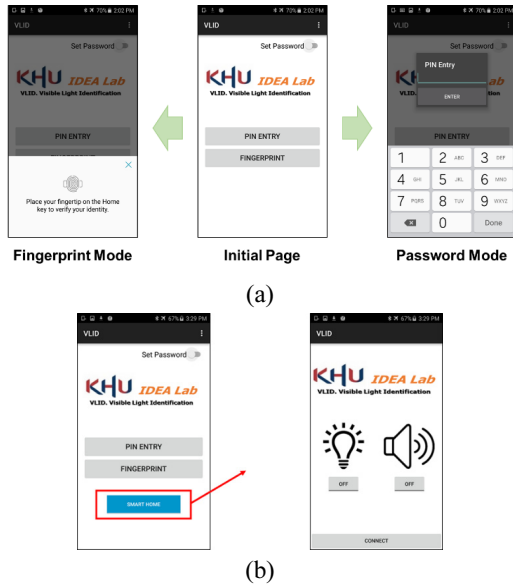


FIG. 6. VLID application program: (a) Password entering pages; (b) Smart home control pages.

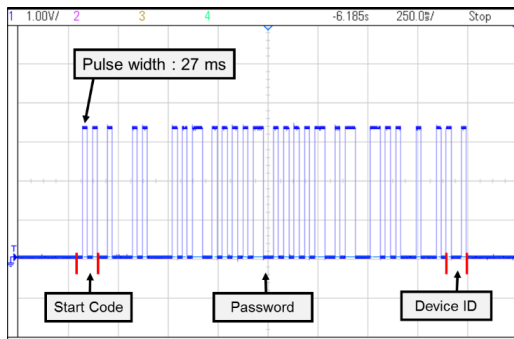


FIG. 7. Output waveform at a comparator of a VLID receiver.

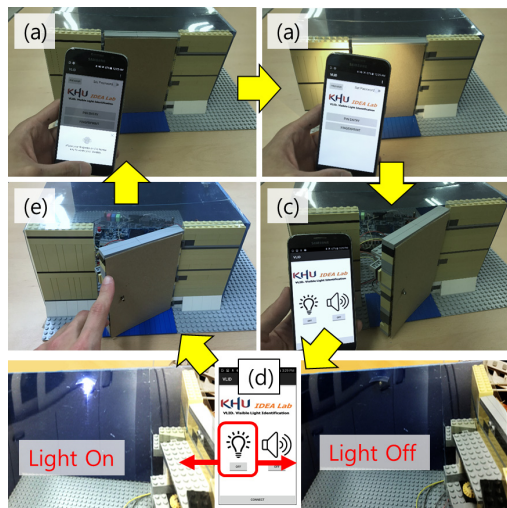


FIG. 8. Procedure of VLID door lock operation: (a) User identification on smartphone; (b) Visible light generation (c) Door opening after authentication; (d) Control smart home via Bluetooth; (e) Door closing and locking.

code is updated. In this stage, the user can control an LED lighting and an audio system of a smart home system using the smartphone. In the end, when the door is closed, the VLID door lock system waits for a next access at the first stage.

To evaluate the performance of the proposed VLID system, the connection failures are counted over 10 participants at the distance of 10 cm between the smartphone and the prototype door lock. The experiments have been conducted in a normal office environment under fluorescent lamps. All participants who are 8 male and 2 female graduate students with the ages from 24 to 30 have used a single smartphone without any other restrictions except the distance. Each participant executes the connecting operation 50 times and the number of failures is measured as summarized in Table 1.

The average rate of connection errors is 2%, where 6 participants show zero error rates especially. Non-zero error rates that are lower than 10% might be caused due to uncontrollable multi-tasking operations of the Android operating system (OS). The multi-tasking conditions can generate the large pulse width variance on the transmitted light signals that leads to the malfunction of the CDR circuit.

Thanks to the simple receiver architecture and the use of a powerful smartphone as a transmitter, the proposed VLID can cover various applications that need security apparatus such as cars, strongboxes, toys, and so on. Also, the VLID system is easy to upgrade because any upgrade is not required for receiver side if there's no modification of VLC interface between a smartphone and VLID receiver and new high performance smartphone models are released every six months and most people are changing their smartphones within two years.

One drawback of VLID technology is the low data rate. The prototype system could turn on and off a flash LED only up to around 40 Hz due to the flashing frequency limit of a smartphone. However, the slow modulation of 40 Hz is caused by software, but not by hardware. LEDs can support higher modulation speed of tens of kHz. Therefore, if some flash LED applications of high modulation frequency such as VLID are demanded, such high frequency flashing functions would be realized easily in future smartphones.

TABLE 1. Error rates of VLID connection are evaluated over 10 participants with 50 trials each.

Participant	Error rate	Participant	Error rate
#1	0%	#6	8%
#2	0%	#7	0%
#3	0%	#8	2%
#4	6%	#9	0%
#5	0%	#10	4%
		Average	2%

IV. CONCLUSIONS

We have demonstrated a prototype visible light identification system for a door lock application with the small area of an outdoor interface. Because VLID makes use of visible light as communication medium, the installation cost is low, compared to other wireless communication schemes. In addition, security system and powerful processor of a smartphone are employed as a VLID transmitter, which allows the door lock system to be upgraded easily without any additional cost and modification. Furthermore, higher security has been achieved by updating the password every VLID operation through a Bluetooth link that allows a user to connect to the smart home hub automatically.

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