Two Hybrid Positioning System Design Techniques with Lighting LEDs and Ad-hoc Wireless Network

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Abstract — Two design techniques for more accurate and more convenient hybrid positioning system with visible light communication (VLC) and ad-hoc wireless network infrastructure are proposed, in order to overcome the problems of high estimation error, high cost, and limited service range of the conventional positioning techniques. First method is based on a non-carrier VLC based hybrid positioning technique for applications involving of low data rate optical sensing and narrow-range visible light reception from transmitter, and long-range positioning. The second method uses a 4 MHz carrier VLC-based hybrid positioning technique for a high data rate optical sensing and wide-range visible light receiving from transmitter, and mid-range positioning applications.

In indoor environments with obstacles where there are long-range 77.314m and mid-range 23.68m distances between an observer and a target respectively, the hybrid positioning systems developed with two design techniques are tested, and measured results are analyzed and presented in this paper.

Index Terms — Hybrid Positioning, Visible Light Communication, Zigbee Ad-hoc Wireless Network, Multi-hop Transmission

I. INTRODUCTION

Most of current positioning technologies used to determine the position of an object are wireless IT based methods that use the basic infrastructures of GPS and cellular communication or the infrastructure of indoor communications based on wireless local area networks. Positioning methods other than wireless based ones include ultrasonic system, infrared system, or video based positioning system, most of which require improvement in estimation accuracy, cost reduction in installing the system infrastructure, and extension of position service area, etc. Hence, searching for a new positioning technology that meets all the requirements is necessary and is ongoing in various fields [1-2]. On the other hand, as one of the environmentally-friendly research areas, recent investigations on visible light (VL) applications are actively being pursued in various fields, in order to contrive a new service from a hybrid of LED lighting and wireless technology [3-6]. Research on VL Communications (VLC)-based positioning to look for a target position by using lighting LEDs and indoor wireless networking has recently started [7-8]. Positioning is mostly used with techniques to seek the target position by converting an estimated value of the received signal parameter (e.g., signal strength, direction, or arrival time) into the distance between a known reference point and a target in the indoor or outdoor environment. The conventional techniques have usually difficulties due to the problems such as position estimation error, a high-cost infrastructure, or a limited service area [9].

In this work, as an updated and expanded version of the previous research results [10], in order to overcome the conventional positioning problems, improve especially the positioning accuracy, and expand the service area, a new hybrid positioning methodology is proposed. Two design techniques for an environmentally-friendly based positioning system are proposed and developed. These methods use a hybrid of VLC scheme with extremely low reception error and Zigbee mesh wireless network. Methods require a low power, offer security and a large service area due to the inferential expansion capability. Positioning Method-I is a non-carrier VLC-based technique for application services of a low data rate optical sensing and narrow-range VL reception from transmitter, and a long-range hybrid positioning, e.g., service for tracking of goods or surveillance at large shopping malls [11-12]. Positioning Method-II is a 4 MHz VLC carrier-based technique for a high optical rate data sensing and wide-range VL receiving from transmitter, and mid-range hybrid positioning, e.g., local broadcasting service or navigation with video terminals [13-14].

In Section 1, we described the challenges in conventional positioning methods and the motivation of the LED based positioning research. In Section 2, we propose the hybrid positioning methodology based on LED technologies, and present the signal model and signal estimation techniques in the environment of VL and wireless network channels. In Section 3, we present an architecture for the proposed hybrid positioning system, the non-carrier and 4 MHz carrier VLC transceiver architectures, and system operation aspects. In Section 4, we describe an implementation of the proposed system, circuit designs, and the algorithms for the two positioning experiments. Conclusions are presented in Section 5.
II. Positioning Methodology and Signal Estimation

The conventional positioning techniques, such as finger print based or cell based position positioning, are wireless positioning, based on GPS and cellular wireless communications. These use proximity estimation method that determines the position of an object as reference position of beacon or signal post located near the object on a map [2]. The proximity estimation method carries the estimation error arising from reception of a distorted signal by indoor and outdoor wireless communications channel as well as any error from proximity estimation. In this work, we use the proximity positioning concept in a hybrid environment of VL and wireless radio frequency communications channels in order to reduce position estimation error caused by any nearby wireless signal.

A. Methodology

The hybrid positioning methodology proposed in this work is shown in Fig. 1. This uses a hybrid proximity based positioning algorithm. In a building with many office rooms, the positioning methodology used to identify the target node position away from the node at the system controller in Fig. 1 is as follows.

![Fig. 1. Hybrid positioning method with VLC scheme and ad-hoc wireless networking including main, relay, and monitoring nodes.](image)

First, VL identification data (ID) is generated along with illumination, and the position information from lighting LED lamp A is received by a photodiode module of the target node (i.e., monitoring node). The received ID is reconstructed and processed as a digital VL ID data that can be transferred to an ad-hoc wireless network via a Zigbee transceiver module. The router nodes with the Zigbee transceiver transfer the VL ID information to the main node through a multi-hop transmission. ID data with position information is then displayed on a system controller screen connected to the main node. When viewed from the Zigbee wireless side, the VL ID information received from the target node is transmitted again via the node that has the function as a router for the relay nodes in the Zigbee wireless network. Finally, the main node which has the function as a Zigbee coordinator and system controller receives the information and displays the results of positioning (i.e., the presence of the target node in office A) on the screen of the system controller. Major specifications of the proposed system are also shown in Table I.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
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<tbody>
<tr>
<td>VL module</td>
<td>LED, Photodiode, 0.33-3.08 m between the center of LED array and VL receiver, Non-carrier/4 MHz Carrier modulation, on off keying/OOK modulation, non return to zero/NRZ data format</td>
</tr>
<tr>
<td>wireless module</td>
<td>IEEE 802.15.4(PHY/MAC layers), Zigbee 2006(NWK/ZDO/AF layers), 2.4 GHz/16 channel/ direct sequence spread spectrum (DSSS)-offset quadrature phase keying (QPSK), 250 kbps/chip rate 2 Mops</td>
</tr>
<tr>
<td>overall system</td>
<td>115kbps between monitoring node and system controller, multi-hop transmission</td>
</tr>
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</table>

B. Signal Estimation under Hybrid Channel

In Fig. 1, reception of the VL ID information is performed not in the radio frequency Zigbee, but rather in the VL signal channel with a wavelength of 380 nm to 780 nm. The ID information sent from a VL signal transmitter of an array of LEDs informs the approximate position of the transmitter and can be written as a K-bit binary digital data in the form of

\[ x(t) = \sum_{j=0}^{K-1} A_j p(t - jT) \]

where \( A_j \) is the signal intensity, \( p(\cdot) \) is the pulse shape, and \( T \) is the duration of a bit. The VL signal channel in Fig. 1 between transmitter of an array of LEDs and the receiver of photodiode consists of a direct path as well as multiple reflected paths due to reflections from many reflectors. Referring to the result of the previous works [15]-[17], the impulse response \( h(t) \) in Fig. 1 can be expressed as:

\[ h_{vf}(t) = h_{LOS}(t) + h_{Diff}(t - \tau) \]

where \( h_{LOS} \) is the channel gain of the direct path signal, \( h_{Diff} \) is the channel gain of the reflected path signal, \( \delta(\cdot) \) is an impulse function, \( \tau \) is the time difference between the direct path signal and the reflected path signal when arrived at the VL signal receiver. The characteristics of channel impulse response \( h(t) \) in Fig. 1 may vary. However, the function of the system depicted in Fig. 1 is not data communication; rather it is estimation of an object position. Also, we note that the distance between the transmitter and receiver of the VL signal channel is short and only a few pulses need to be transferred mainly through the direct path. Therefore, the VL signal channel impulse response of (2) can be simplified by neglecting the reflected paths transmission as:

\[ h_{vf}(t) = h_{LOS}(t) \]

Let \( G(\psi) \) and \( \gamma(\psi) \) be the gain of an optical filter and the gain of an optical concentrator and the receiving area of the VL signal of a photodiode. Let \( \psi \) be the incident angle. We assume that the incident angle is within the range of receiver Field-of-View (FoV), \( \psi_C \) that is; \[ 0 \leq \psi \leq \psi_C \] .
Assuming VL of LED is of diffuse nature with a Lambertian emission pattern, the light intensity of an LED VL in the angle of irradiance $\phi$ is given by

$$I(\phi) = \frac{1 + m}{2\pi} \cos^m(\phi) \tag{4}$$

where $m$ is the order of Lambertian emission such that $m = \ln(1/2)/\ln(\cos(\varphi_1/2))$ where $\varphi_1/2$ is the half-power angle of lighting LED. If $\varphi_1/2 = 60^\circ$ then $m = 1$, and (4) can be simplified as $I(\phi) = \frac{1}{\pi} \cos(\phi)$. The transmitted power of the VL transmitter, $P_T$, is given by:

$$P_T = I(\phi)P_{LED} \tag{5}$$

where $P_{LED}$ is the power of an array of LEDs. The direct path channel gain is given by

$$h_{idc}(t) = \frac{1}{D^2} I(\phi)G(\psi)G(\psi')S \delta(t) \tag{6}$$

then the received signal can be written from (1) and (6) as $y_{idc}(t) = x(t) * h_{idc}(t) + n(t)$, i.e.,

$$y_{idc}(t) = \frac{1}{D^2} (I(\phi)\cos(\psi)G(\psi)G(\psi')S \sum_{j=0}^{K-1} A_j p_t(t - jT) + n(t) \tag{7}$$

where $n(t)$ is an additive Gaussian noise with a zero mean and unity variance.

In Fig. 1, when the target node is near the LED light $A$ in office $A$, node carrying the VL signal of the intended receiver, the ID information, can receive the VL ID (OA)$_{m=1}$ or $K$-bit VL ID information of (1), emitted from the LED array lamp $A$, and detects the position of the target office. The received signal, as shown in (7), depends on the angle of incidence, $\psi$, the light intensity $I(\phi)$, and square of the distance between a transmitter and a receiver, $D^2$. When the target node moves to office $N$, it receives the VL ID (0N)$_{m=1}$ transmitted from an LED light in office $N$, and identifies the information of current position. Then, a parameter identifying the Received Signal Strength (RSS) in positioning for VL ID signal, $m_{idc}$, can be estimated through, for example, the sample-mean estimation method through $Q$-trials as:

$$m_{idc} = \frac{1}{Q} \sum_{i=0}^{Q-1} y_{idc}^{(i)}(t). \tag{8}$$

Therefore, the signal estimate is obtained from the received signal strength, (8), of the VL position ID data at target (monitoring) node through VL channel.

In Fig. 1, the ID digital data, the position information, can be transferred to the Zigbee wireless network via the target node carrying the functions of Zigbee wireless transmission and reception. The received VL ID signal is transformed, passing through the target node, from the original $K$-bit binary digital information to the signal as follows:

$$x_j(t) = \sum_{j=0}^{K-1} B_j p_x(t - jT_s) \tag{9}$$

where $B_j$ is the transformed signal intensity, $p_x(t)$ is the pulse shape representing the independent data bits, and $T_s$ is the duration of a Zigbee digital data bit.

When the Zigbee transceiver of the target node in the hybrid positioning system in Fig. 1 transmits the binary digital data of VL ID information to the relay nodes, the communications characteristics follow the 2.4 GHz narrow-band indoor wireless channel, i.e. the characteristics of general narrow-band indoor wireless channel model. Also, the impulse response of the Zigbee channel can be written as

$$h_z(t) = \sum_{i=0}^{M-1} \sum_{m=0}^{Z-1} a_{i,m} \delta(t - \tau_{i,m}) \tag{10}$$

where $a_{i,m}$, $\tau_{i,m}$ are the signal magnitude and arrival time of the $i$-th path in the $m$-th cluster, respectively. $M$ is the number of cluster, and $Z$ is the number of the multipath terms in the cluster.

Assume that a Zigbee pulse generated by a transmitter passes through the narrowband indoor wireless channel such that $Z$ multipath components in the $M$ clusters arrive at the Zigbee receiver of the relay node. Depending on the real channel situations, the number of clusters can be less or greater than $M$. When the transmitted Zigbee signal arrives at the receiver of the relay node, the received signal can be written from (9) and (10) as $y_z(t) = x_z(t) * h_z(t) + n(t)$, i.e.,

$$y_z(t) = \sum_{i=0}^{M-1} \sum_{m=0}^{Z-1} a_{i,m} B_j p_z(t - jT_z - \tau_{i,m}) + n(t) \tag{11}$$

After $Q$-trials experiments, the estimation value of the received signal strength (RSS) parametric variable is given by

$$m_z = \frac{1}{Q} \sum_{i=0}^{Q-1} y_z^{(i)}(t). \tag{12}$$

The signal estimate of the position ID data at main or relay node through ad-hoc wireless network channel with impulse response $h_z(t)$ is obtained from (12).

### III. SYSTEM ARCHITECTURE AND OPERATION

#### A. Overall System Architecture

In order to develop a hybrid positioning system, the entire system is arranged as illustrated in Fig. 2. The PC based system controller is connected to the main node via a serial communication interface. The main node constructs a network in Zigbee and functions as a coordinator assigning network addresses. The relay node functions as a router in the Zigbee and shares the network address that is assigned by the coordinator. The monitoring node connects to the Zigbee and shares the network address assigned by the coordinator.
B. Visible Light Communication Architecture

The detailed configuration of VL transmitter and receiver in the entire system arrangement of Fig. 2 are depicted in Fig. 4 and Fig. 5.

In the VL ID transmitter in Fig. 2, binary data from a PC passes through the RS232 driving circuit and LED driving circuit, and drives LEDs. Then the VL ID signal passes through VL channel, and is received by a VL ID receiver that consists of optical concentrator, photodiode, and a signal amplifier. The received signal passes the driving circuits in the receiver and is reconstructed into binary digital data through demodulation process.

Non-carrier VLC-based transceiver architecture is shown in Fig. 4. In transmitter of Fig. 4(a), position ID information is converted into binary NRZ input data, and the VL signal is produced only when the binary data is '1', which is used with OOK modulation without carrier. The transmitted VL signal is received by the receiver and the VL signal is demodulated by use of a non-coherent detection scheme, and the original NRZ data is obtained. The NRZ data is again converted into the position ID data through RS232 driver circuit, and transferred to the monitoring node in a serial communication method.
maximum 250 kbps. A narrowband wireless channel via a whip antenna at a speed of 2.4 GHz is used. The Zigbee signal is emitted into the channel and processed by the DSSS and OQPSK modulation in the Zigbee module based on the IEEE 802.15.4 standard. It is fed to the serial port of the Zigbee transmitter/receiver module. Zigbee information written to the monitoring node is given as (9) and is fed to the input of the VLC service.

The operating procedures of hybrid positioning system of Fig. 2 designed to follow the given methodology is illustrated in Fig. 6 from the point of view of operation sequence. In detail, the positioning algorithm operation starts from the supply of power to the monitoring node and main node. After initialization of the modules and network binding process between the Zigbee transceiver modules in the monitoring node and the main node, a Zigbee wireless network is constructed between these and the wireless data can be transmitted through the network. The VL ID transmitter, connected to a PC, transforms the 8 bit VL ID data that is generated in PC and contains position information written in non-carrier or 4 MHz carrier OOK-NRZ format and emits data via an LED light in the visible light channel that has Lambertian characteristics and 380 nm-780 nm wavelength range in every 100 msec. The VL ID receiver in the monitoring node receives the VL signal passed through the minimum distance path in line-of-sight range and attenuated by path loss given by (7), using general optical filters and optical concentrator. It filters the VL ID signal using a band pass filter and reconstructs the original 8 bit digital data, periodically.

The 8 bit digital data generated from the VL ID receiver of the monitoring node and given as (9) goes to the input serial port of the Zigbee transmitter/receiver module. Zigbee modules are based on the IEEE 802.15.4 standard. It is processed by the DSSS and OQPSK modulation in the Zigbee modem and a Zigbee signal is emitted into 2.4 GHz narrowband wireless channel via a whip antenna at a speed of maximum 250 kbps.

IV. SYSTEM IMPLEMENTATION AND EXPERIMENT

A. Developed Prototype

A prototype for hybrid positioning system is constructed to realize the proposed hybrid positioning methodology of Fig. 1. Fig. 7 shows the entire view of the implemented hybrid positioning system. According to the proposed methodology of Fig. 1, the system consists of a PC to generate the position information for VL ID transmission, VL ID transmitter and receiver, Zigbee nodes — e.g. monitoring node, relay node, and main node in Fig. 7 - for wireless network data transmission, a system controller PC to run the user interface program that shows the positioning results, and a Zigbee protocol analyzer. The center PC in Fig. 7 shows the positioning results on screen, and the PC on the right side in Fig. 7 allows observation of the constructed network environment, i.e., Zigbee multi-hop wireless network.
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Fig. 7. Overall view of the developed prototype for hybrid positioning.

Then, the VL ID transmitter, connected to a PC as shown in Fig. 7, transforms the 8 bit ID data that is generated in PC and contains position information in the NRZ data format and emits data via a white LED array in the channel that has a Lambertian characteristics and 380nm-780nm wavelength range, periodically. The VL ID receiver, connected to the monitoring node in Fig. 7, receives the VL signal. It filters the VL ID signal using a band pass filter and reconstructs the original 8 bit digital data, periodically. The 8 bit digital data generated goes to the input serial port of the Zigbee module. It is processed by DSSS/OQPSK modulation in the Zigbee modem and a Zigbee signal is emitted into 2.4 GHz wireless channel via a whip antenna at a maximum speed of 250 kbps. The transceiver of the main node in Fig. 7 receives the Zigbee signal and demodulates it in order to obtain the 8 bit digital data, which is then passed again to the system controller in Fig. 7 through a serial port. The position of the monitoring node is determined and displayed on the controller in Fig. 7.

In order to expand the range of positioning, we extend the distance between the monitoring node and main node and place relay nodes in Fig. 7 operating in between them to construct a Zigbee wireless network with a multi-hop function. The procedures restart again from the beginning.

B. Circuit Design and Analysis

In order to design the optimal VL transceiver for more accurate and more convenient hybrid positioning system, two design techniques are considered as shown in Fig. 4 and Fig. 5, which are the non-carrier VLC based and the 4 MHz carrier VLC based transceiver architectures. According to the proposed VLC architectures, the transmitter and receiver circuits have actually been designed for hybrid positioning systems, and represented in Fig. 8 and Fig. 9, respectively. Subsequently, hybrid positioning with prototype implemented in accordance with the designed circuit were done.

Also, the VL receiving distance from transmitter has been analyzed depending on the VLC transceiver circuits. The experiments have been done with the non-carrier VLC based transceiver circuit of Fig. 8 and the 4 MHz carrier based VLC transceiver circuit of Fig. 9 and device specifications of the circuits are as follows. For transmitter, light emitting component is a 3x3 high brightness white LED array, the LED driving circuit is an NPN transistor, and the data buffer is implemented by normal AND and NOT gates. For receiver, there is a photodiode, and a non-inverting amplifier circuit with 0 dB gain is realized by a normal low noise amplifier IC. The receiver with functions of band pass filter and signal detection (demodulation), and a 4 MHz oscillator were installed for a 4 MHz carrier VLC-based transceiver.

The experimental results are shown in Fig. 10, where it can be seen that the non-carrier based VL transceiver circuit provided the error-free VLC transmission results within the narrow-range 0.33-0.403m, and the 4 MHz carrier based VL transceiver circuit showed an error-free transmission within the wide-range 0.0057-0.479m. Also, if the gain G in the transceiver circuits of Fig. 8 or 9 is increased, the VL reception range can be increased to the range 3.08m. These circuits with gain adjustment of G adequate value are applied for the proposed hybrid positioning system of Fig. 7.

C. Hybrid Positioning Experiments

Two hybrid positioning experiments were performed, with a developed prototype as shown in Fig. 7 under the conditions of non-line-of-sight hybrid channel environment, three and five-hop Zigbee wireless network transmissions, and the two VLC schemes – i.e. non-carrier and 4 MHz carrier methods I and II.

Fig. 8. An example for non-carrier VLC based transceiver circuit (a) transmitter (b) receiver.

Fig. 9. An example for 4 MHz carrier VLC based transceiver circuit (a) transmitter (b) receiver.
First, the mid-range hybrid positioning test was performed in an environment that a target is at about 24 m distance with non-line-of-sight condition away from an observer, a VL form of 4 MHz carrier OOK NRZ is provided around a target with Zigbee monitoring node, and an observer is inside the room. The observer is to estimate the target position although the observer cannot see the target, directly.

![Fig. 10. VL reception distance from transmitter depending on the transceiver circuits.](image)

In order to accomplish this, we arranged the experiment as shown in Fig. 11, by introducing a three hop wireless network with 23.68 m distance between the target (i.e., monitoring node of Fig. 11(a)) and the observer (i.e., main node of Fig. 11(c)).

The transferred Zigbee packet data over wireless channel was captured by protocol analyzer (i.e., SNA of Fig. 11(c)), and could be observed for data analysis in Fig. 12. From the received packet data of Fig. 11, we obtained a VL ID data around the target, and the ID data gave us the target position by use of a proximity positioning technique. In addition, we could see the wireless channel condition and the transferring data packet around the area between the target and an observer by use of Zigbee protocol analyzer.

The long-range hybrid positioning experiment was done under the non-line-of-sight environment that a target in the corridor of the third floor of the engineering building as shown in Fig. 13, is away at around 78 m distance from an observer inside the room No. 1319 of the same building, where a VL transceiver of non-carrier OOK NRZ scheme is provided the position data around a target in front of room No. 1351.

To create the conditions for testing estimation of target at a distance, the additional nodes of relay function – i.e. Relay installed at three sites in front of rooms No. 1344, No. 1339, and No. Node-1, Relay Node-2, and Relay Node-3 were 1326, respectively, as shown in Fig. 12. Also, the Zigbee signal detector and protocol analyzer were set around the system controller in order to observe the Zigbee signal packets and the binding process among the nodes.

We planned to perform the five hop hybrid positioning experiment according to the hybrid positioning methodology in Fig. 6 as follows. When the PCs, the main and monitoring nodes around room No. 1319 are in power on mode, the Zigbee binding process between two nodes is done and checked by use of Zigbee protocol analyzer. Also, a VL transmitter is used and the position data generated from PC (in the right side of Fig. 13) is transferred to the VL receiver over VL channel.

Then the received signal is converted into a digital data by monitoring node, the Zigbee wireless signal with a 2.4 GHz OQPSK-DSSS form is again converted, and the RF signal is transferred into the main node over wireless channel. After the main node receives the transferred RF signal, the reverse process of the operation of the monitoring node is done, the recovered position data is finally displayed on the PC in the left side of Fig. 13, and the system operation for the hybrid positioning is continuously repeated.

In order to expand the positioning area, Relay Node-3 is inserted and operated in front of room No. 1326 for a three hop wireless network transmission after the VL transceiver, PC for data generation, and the monitoring node are moved in front of room No. 1339. Also, in order to have more extension, Relay Node-2 is inserted in front of room No. 1339 for a four hop wireless network transmission, and Relay Node 1 is inserted in front of room No. 1344 for a five hop transmission.
In order to observe the mesh wireless network connection and to analyze Zigbee data packets and protocol, we obtained the results of Fig. 14 by use of Zigbee signal detector and protocol analyzer. From Fig. 14, we can see and verify that the five hop wireless network transmission was well operated, the position data around a target was well estimated at the observer, and finally the five hop wireless network-based hybrid positioning test was successfully done.

V. CONCLUSIONS

By use of a hybrid of VLC scheme with extremely low reception error and Zigbee mesh wireless network of having characteristics of being portable, low power, good security, and a large service area due to the inferential expansion capability, two design techniques for convenient and accurate hybrid positioning system were proposed and developed. The methodology and signal estimation algorithm, the overall system and VLC architectures, and the system operation, of proposed technique were introduced, successively.

The proximity positioning concept was used in a hybrid environment of VL and Zigbee radio frequency channels to reduce the position estimation error caused from nearby wireless channels. The signal source estimate was obtained from the received signal strength of the VL position ID signal at monitoring node. The wireless position ID signal at the main or relay node could also be estimated from the received signal strength of Zigbee signal through ad-hoc wireless network channel. The non-carrier VLC based transceiver scheme is more suitable for long-range and low data rate optical positioning because of simple circuits and lack of a carrier. It, however, has the drawback of low frequency noise and a narrow-range of VL reception.

The 4 MHz carrier VLC-based transceiver scheme is more suitable to the mid or short-range and high optical data rate positioning because of its robustness against noise and a wide-range VL reception.

From experiments, it can be seen that the 4 MHz carrier based VLC circuit provides error-free transmission within a VL reception range wider than the non-carrier based VLC circuit. The mid-range and long-range hybrid positioning with the proposed techniques were well done under an indoor obstacle environment where there is 23.68 m and 77.314 m distances between an observer and the target, respectively. Also, the position ID data and its communication protocol performance over channels were analyzed and verified.

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**BIOGRAPHIES**

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