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Visible Light-based Outdoor Navigation Systems for Visually Impaired People

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ABSTRAK

Dalam penelitian ini dilakukan perancangan dan implementasi prototipe alat bantu orientasi dan mobilitas bagi tunanetra pada media perlintasan, khususnya zebra cross dengan menggunakan sistem Visible Light Communication (VLC). Perangkat yang diimplementasikan adalah prototipe zebra cross yang terdiri atas rangkaian pemancar VLC dan rangkaian penerima VLC. berupa prototipe tongkat bagi tunanetra. Pada penelitian ini, evaluasi sistem mempertimbangkan parameter jarak, sudut, dan kondisi lingkungan di zebra cross. Pengukuran juga mempertimbangkan intensitas cahaya pada kondisi siang hari dan malam hari. Berdasarkan hasil pengukuran diketahui bahwa sistem mempunyai kinerja yang baik, dengan tegangan keluaran maksimum sebesar 4,88 volt pada jarak 10 cm dengan sudut 90°, dengan hasil optimal didapatkan pada pada malam hari dengan tegangan 3,88 volt.

Kata kunci*: Outdoor, Visible Light Communication (VLC), Tunanetra, Zebracross*

ABSTRACT

In this paper, the design and implementation of prototypes of orientation and mobility aids for the visually impaired in outdoor environments, especially zebra crossings, were carried out using the Visible Light Communication (VLC) system. The devices implemented are a zebra crossing prototype in which there are a VLC transmitter circuit and a blind prototype stick, which includes a VLC receiver circuit. The system evaluation considers parameters the distance, angles, and environmental conditions in the zebra crossing. The measurement was carried out for two types of environmental conditions, i.e., conditions during the day and night. Based on the measurement results, it was found that the system has a good performance, with a maximum output voltage of 4.88 volts at a distance of 10 cm with an angle of 90°, while the system has a better result at night with an output voltage value of 3.88 volts.

Keywords*: Outdoor, Visible Light Communication (VLC), Visually Impaired, Zebra Cross*

1. PENDAHULUAN

The vision is very influential on the activities of human life every day. Several of the information required can be obtained through the vision. When going to activities directly related to the vision, it will reduce the performance even if the activity cannot be done. One of its activities is walking. Orientation and mobility aids that can be expected for the visually impaired is a device that can provide convenience supported by adequate facilities and infrastructure. The aids that are commonly used when walking is blind stick due to practical and inexpensive. Usually, the blind stick is used to check the underside's condition of the walking path whether there is a disruption in front of them. Problems arise when going across the zebra cross because no path guides the crossing zebra cross. Therefore, it will be designed for orientation and mobility aids for the visually impaired in the zebra cross with Visible Light Communication (VLC) technology.

Some studies have been conducted to facilitate the visually impaired person in carrying out their activities using several sensors. Bansevicius et al. implemented an electromagnetic screen for visually impaired persons **(Bansevičius et al., 2011)**. When visually impaired people move a thin ferromagnetic disk on an electromagnetic screen by their finger, it feels the friction force variation due to the magnetic field's control and frequency variation. And Kovacs et al. was helping visually impaired people in orientation using ultrasonic devices **(Kovács and Nagy, 2020)**. It showed that the device is applicable for their activity purposes.

Recently, Visible Light Communication (VLC) technology have been implemented in many applications. Kristiana performed the feasibility of VLC in Vehicle-to-Vehicle (V2V) communication using the VLC-VN algorithm **(Kristiana et al., 2020)**. The VLC-VN algorithm was designed to overcome the VLC compatibility in a vehicular network and communication between the vehicles. And Darlis et al. **(Darlis et al., 2020)** proposed bidirectional video communication using visible light communication. The system employs a bidirectional method where each of the Red, Green, and Blue (RGB) filters represents respective wavelengths in each link. The system is a reliable bidirectional visible light communication system for video transmission. The research showed that video transmissions are possible using visible light medium.

The other research were conducted navigation system for visually impaired people in the indoor environment. Yusof et al. **(Yusof et al., 2015)** developed a path planning method using the PSO algorithm. The technique will give the visually impaired people the shortest route to the destination. The simulation result shows that the PSO algorithm will significantly solve path planning with each place's constraint is visited exactly once. In comparison, Darlis et al. **(Darlis et al., 2021)** and Jayakody et al. **(Jayadody et al., 2021)**, Nikhil et al. **(Nikhil et al., 2019)** proposed light follower systems for the visually impaired using visible light. The system can facilitate visually impaired people to determine orientation and support mobility in an indoor situation using visible light.

In another research, Perez-Jimenez et al. **(Perez-Jimenez et al., 2017)** and Nakajima et al. **(Nakajima and Haruyama, 2013)** explored different alternatives for visually impaired people's mobility problems using wireless optical communications. It showed how smartphone cameras are used as guidance technology for visually impaired people in indoor scenarios.

Then, Ko et al. **(Ko and Kim, 2017)** developed the system to help visually impaired people recognize their location and find their way to a given destination in an unfamiliar indoor environment. And Mahida et al. **(Mahida et al., 2020)** focused on the positioning of a person with enough precision for their use in indoor navigation. And Kaur et al. **(Kaur and Garg, 2021)** evaluated several technologies used for detecting obstacles for blind persons have been reviewed. It observed that significant improvements are required in existing systems to operate accurately in crowded areas such as supermarkets, hospitals, airports, etc. Also, some techniques yield accurate results but take more time during execution, thereby making the systems unfit for real-time situations.

Kii et al. constructed a pedestrian support system using visible-light communication with self-illuminated bollards in outdoor applications **(Elmannai et al., 2017)**. In this study, a measurement result was performed in a dark room to design a night's pedestrian support system. However, this study does not consider daytime conditions for the dominant activities of the visually impaired.

In the proposed system, the visually impaired navigation system will be implemented in the outdoor environment, especially on zebra cross-system and measurement considering the distance, angles, and environmental conditions in the zebra crossing, especially during day and night utilize visible light communication. This system will be useful as a navigation system for visually impaired people crossing the road using a zebra crossing.

2. METHODS

The design and implementation of orientation and mobility aids using Visible Light Communication (VLC) system are divided into two main parts, i.e., the design and implementation of VLC transmitter on zebra cross and a VLC receiver in the blind stick. In general, the system is designed with a diagram block in Figure 1, which consists of a VLC transmitter that transmits an audio information signal from the audio generator, then is sent by the LED light in the zebra cross prototype. The LED function is to convert electrical energy into light, and the type of LED used in this research is a LED module in a VLC transmitter. The LED's light contains an information signal transmitted through the medium light in the air and received by the photodiode in the VLC receiver circuit.

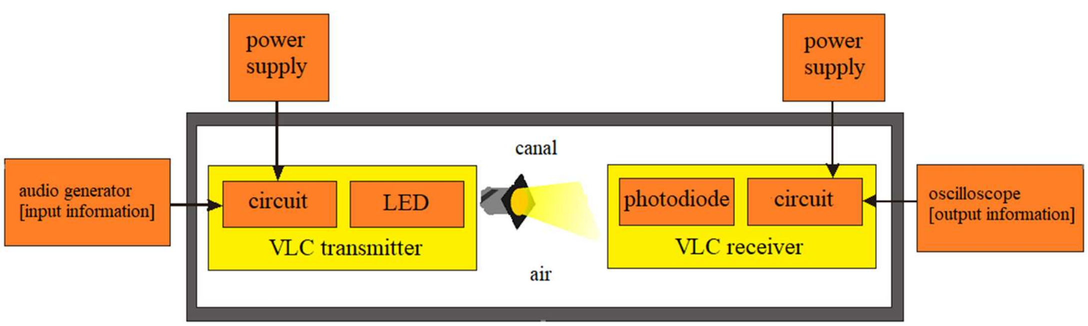


Figure 1. Block Diagram of the System (Darlis et al., 2020)

The information signal is generated from an audio generator with a voltage of 5 volts, and the supply voltage at the input of the LED is 12 volts. The VLC transmitter circuit functions as a carrier for the input signal, which simultaneously connects the input signal with the LED so that the LED can process it. Thus, the light produced by the LED contains information. The LEDs convert electrical quantities into a light, so it can be called light modulation. The Photodiodes in the VLC receiver convert the light into electrical and as a signal receiver in this block. The VLC receiver circuit is used to detect the presence of lightwave signals sent by the transmitter. The VLC receiver circuit includes an amplifier which is used to amplify the received signal via a photodiode. The output information signal is used for the output port in the form of audio read by the oscilloscope.

2.1. System Design

The black line in Figure 2 is a canal for LED placed between the small culvert-shaped walls while also functioning as a water canal. LED lights and VLC transmitter circuits are laid out to emit light of information signal from below the road or a zebra cross.

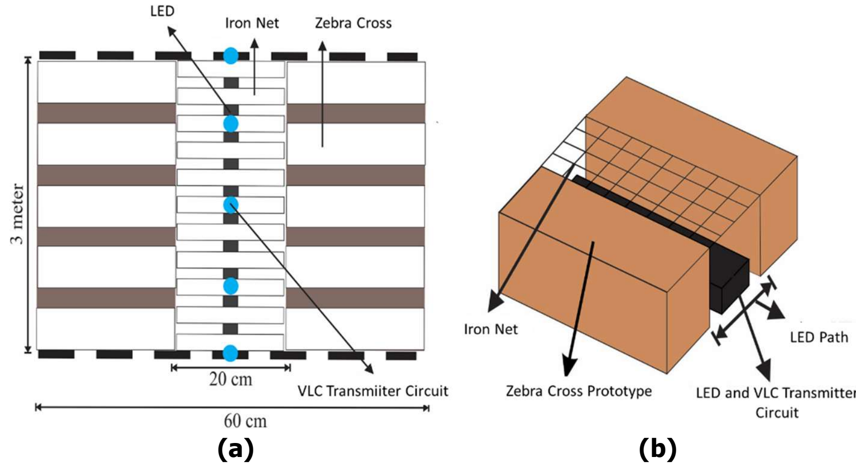


Figure 2. (a) Zebra Cross Prototype Design as Transmitter Looks Upper (b) Zebra Cross Prototype on a Road

There is a photodiode at the bottom of the stick prototype mouthpiece. When faced perpendicular to the light coming from the LED on the zebra cross surface, it functions to receive information. The photodiode is connected to the VLC receiver circuit, and the received signal will be listened via headset in audio form by the visually impaired. It shows in Figure 3.

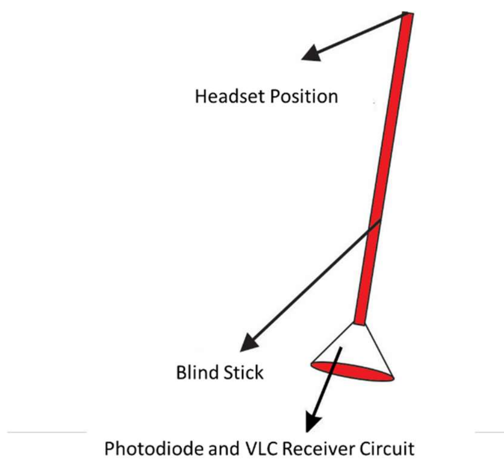


Figure 3. Blind Stick Design as Receiver

The blind sticks are placed just above the zebra cross prototype's surface and placed perpendicularly between the LED lights connected to the VLC transmitter circuit in the zebra cross prototype with a photodiode connected to the VLC receiver circuit in the prototype under the blind stick. Figure 4 shows the integration of VLC transmitter and receiver design.

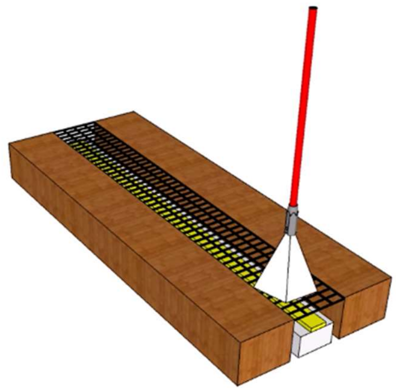


Figure 4. Integration of System Design

Figure 5 shows the entire prototype that has been designed and implemented following real environmental conditions. VLC transmitter along with LED lights are placed on the bottom of the prototype zebra cross. The VLC receiver is placed on the blind stick prototype perpendicular to the LED's light on the zebra cross surface.

Figure 5. Condition of System Application in a Real Environment

VLC transmitter sends the information signal in the form of audio that comes from the sound recording of mp3, the information signal in the form of mp3 audio is inserted on the LED light, which is then transmitted or emitted by the LED light. So, the light from the LED contains an information signal that will guide the blind person walking across the zebra cross. The information will be transmitted via light media with an air canal and received by the photodiode in the VLC receiver circuit. The photodiode's information signal is generated by the receiver VLC system, which can be displayed with the help of a headset mounted on the top of the blind stick prototype. Where the blind will directly hear the information sent through the headset that has been installed. Then will be guided during crossing the zebra cross because of the information that goes through the headset.

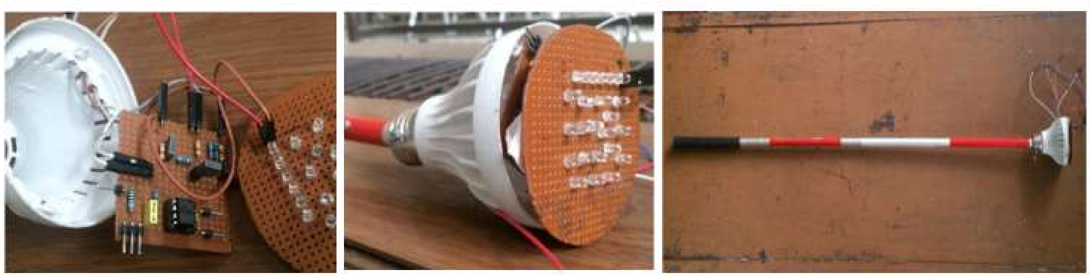
2.2. System Implementation

In the VLC transmitter circuit, information signal changes come from the audio generator into the light. That is by transforming information from the audio generator into a VLC transmitter series, a simple RC filter circuit. The information signal is then converted to light that is channeled by LED, which is still in the VLC transmitter circuit so that LED light contains information. Figure 6 shows the VLC Transmitter implementation.

(a) **(b)** **(c)**

Figure 6. (a) Connecting Transmitter circuit with LED (b) Transmitter Circuits Plotted on the Zebra Cross Prototype (c) Zebra Cross Prototype Complete with Transmitter and Blind Stick Handle

In the VLC receiver circuit, there will be altering the information signal received by a photodiode that will convert into an electrical signal form. Electrical signals in the form of analog signals are converted back into digital information in the form of audio that is connected with a headset located on the blind stick. It shows in Figure 7.



(a) **(b)** **(c)**

Figure 7. (a) Connection of Receiver Circuits with Blind Stick (b) Installing a Receiver Circuit on a Blind Stick Funnel (c) The Integrated Blind Stick

And the connection between the transmitter prototype and the receiver prototype can be seen in Figure 8.

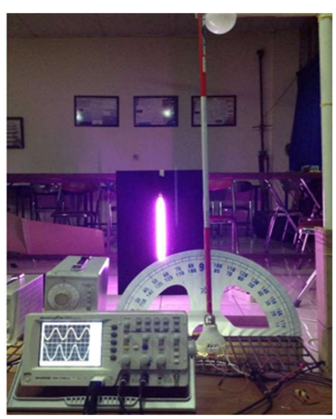


Figure 8. Implementation of Visually Impaired Aids System

3. RESULT AND DISCUSSION

The system of orientation and mobility aids for the visually impaired in the zebra cross using a Visible Light Communication system have been implemented. In this section, the system measurement will be done. The measurement is considering parameters based on distance, angle, and environmental conditions. The purpose of system measurement based on distance is to know the maximum range of the system. While the purpose of the measurement based on the angle and environmental conditions is to find out at what angle the degree of work the VLC system can work well even with some conditions that will be given to the system.

3.1. System Measurement based on Distance

Figure 9 is an overview of the system implementation in measurement and retrieving data on the prototype for sensitivity measurement between VLC transmitter and VLC receiver. With a certain distance to be the measurement, 3 different sizes are 10 cm, 15 cm, and 20 cm. The frequency range used is 300 Hz up to 30,000 Hz. The reference voltage of 5 volts peak to peak. The reference angle is 90º because an angle of 90º is excellent for this measurement reference. LED located on the VLC transmitter circuit with a photodiode located on the perpendicular VLC receiver circuit means the system's sensitivity is best by using a 90º angle. The measurement is done with conditions at night to avoid any interference from ultraviolet/sun rays. Because for measurement to find distance and stable frequency range must be in uninterrupted condition.

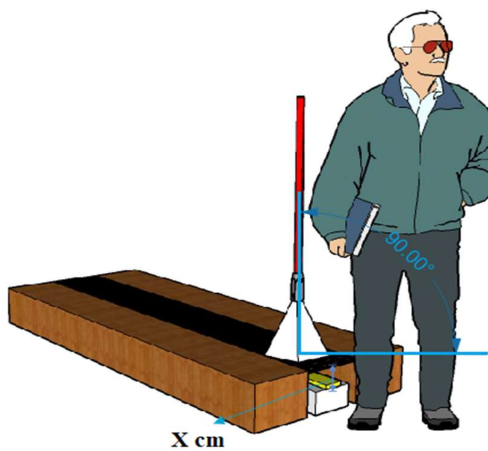


Fig. 9. Transmitter and Receiver Prototype Design for The Distance

Set an angle of 90º between the lower end of the stick and the zebra crossroad surface while the visually impaired hands hold on to the top end of the rod .Install transmitter and receiver with the distance of X cm, as shown in Figure 9. The measurement results of the signal images produced in the oscilloscope are recorded and analyzed.

In measurement, the system based on distance, to see that the VLC system can work properly can be seen in Figure 10.

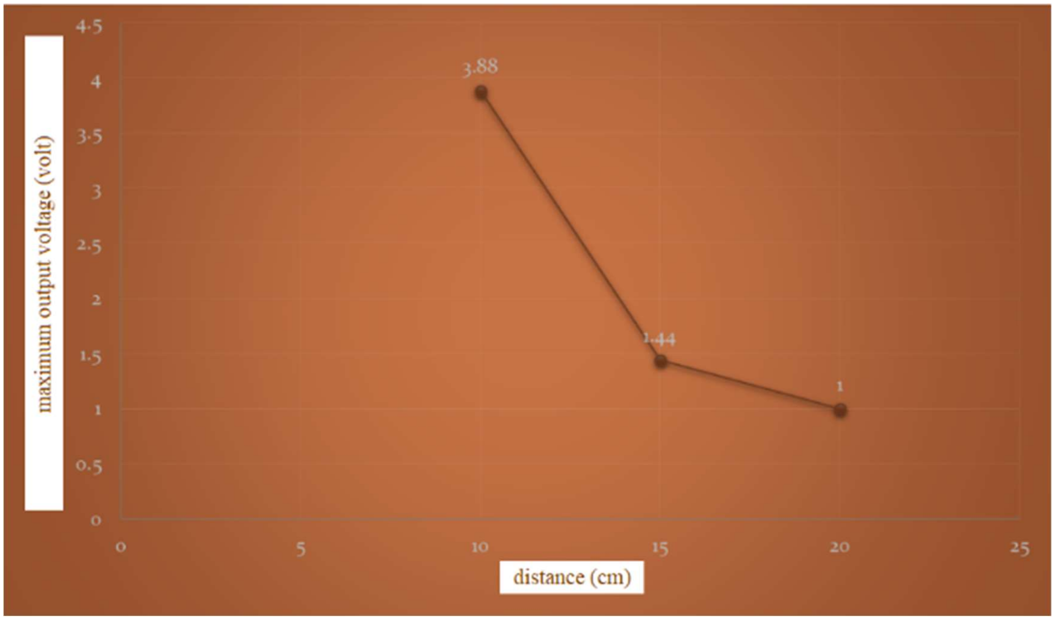


Figure 10. Comparison Chart between Output Voltage and Distance

The measurement in the distance of 10 cm and an angle of 90° at night in the absence of interference obtained for the measured frequency range is 300 Hz to 30,000 Hz. The human voice frequency range is 300 Hz - 3400 Hz for a range of 3000 Hz, VLC systems can work well. With an input frequency of 3094 Hz, the output frequency is 3072 Hz. For input reference voltage is 5 volts peak to peak. The maximum measured output voltage is 800 millivolt peak to peak up to 4.88 volts peak to peak, with a frequency range of 300 Hz - 30.000 Hz. It appears that the higher the frequency between the range of 4.8 kHz - 4.8 MHz, the voltage will be stable because of the frequency filter Band Pass Filter.

The next measurement is 15 cm, three output frequency ranges cannot be read by oscilloscope is 302.9 Hz, 601 Hz, and 912.4 Hz. The human voice frequency range is 300 Hz - 3400 Hz for a range of 3000 Hz VLC systems can work well. With an input frequency of 3034 Hz, the output frequency is 3040 Hz. For input reference voltage is 5 volts peak to peak. The measured output voltage is 320 millivolt peak to peak up to 3.44 volts peak to peak, with frequency range 300 Hz - 30.000 Hz. It appears that the higher the frequency between the range of 4.8 kHz - 4.8 MHz then the voltage will be stable because of the frequency filter BPF.

And the last measurement with distance of 20 cm, 4 output frequency ranges can not be read by oscilloscope that is 305.6 Hz, 596.7 Hz, 914.1 Hz, and 1008 Hz. The human voice frequency range is 300 Hz - 3400 Hz seen in Table 3 for a range of 3000 Hz, VLC systems can work well. With an input frequency of 3019 Hz, the output frequency is 3016 Hz. For input reference voltage is 5 volts peak to peak. The measured output voltage is 320 millivolt peak to peak up to 2.2 volts, with a frequency range of 300 Hz - 30.000 Hz. It is proven that the higher the frequency between the range of 4.8 kHz - 4.8 MHz then the voltage will be stable because of the frequency filter BPF.

The measurement results for three different distances with reference input frequency 3000 Hz found that the maximum output voltage inversely proportional to the distance. As the distance gets larger, the maximal output voltage value becomes small. This means a system with 10 cm is most likely used to reference the system's distance with stable work.

3.2. System Measurement based on Angles and Environmental Conditions

Figure 11 illustrates how measurement for the system based on the angle and environmental conditions is performed.

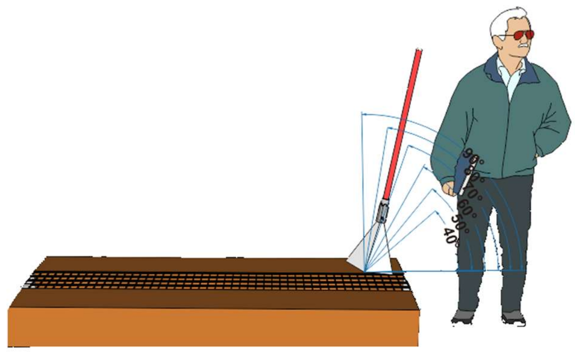


Figure 11. Prototype Design for System Measurement based on Angle And Environmental Conditions

This measurement will be known at the angle of how many degrees the system can work well even with some conditions that will be given to the system. The angle measurement is 90°, 80°, 70°, 60°, 50°, and 40°. The measurement is done by the distance between the transmitter and receiver as far as 10 cm. With a reference frequency of 3000 Hz, the input voltage is 5 volts peak to peak. All measurement is done during the day and night, which means there is sunlight when done during the day, while when done at night, there is no sunlight. What is meant by the disturbance is the vehicle spotlight which when measurement using fluorescent lamps. In measurement, the system based on the angle and environmental conditions, to see that the VLC system can work properly can be seen in Figure 12.

3.3. Measurement Result without Interference during The Day

This measurement aims to find a good range of angles on the VLC system with the distance between the transmitter and receiver as far as 10 cm in the day with the code without any interference.

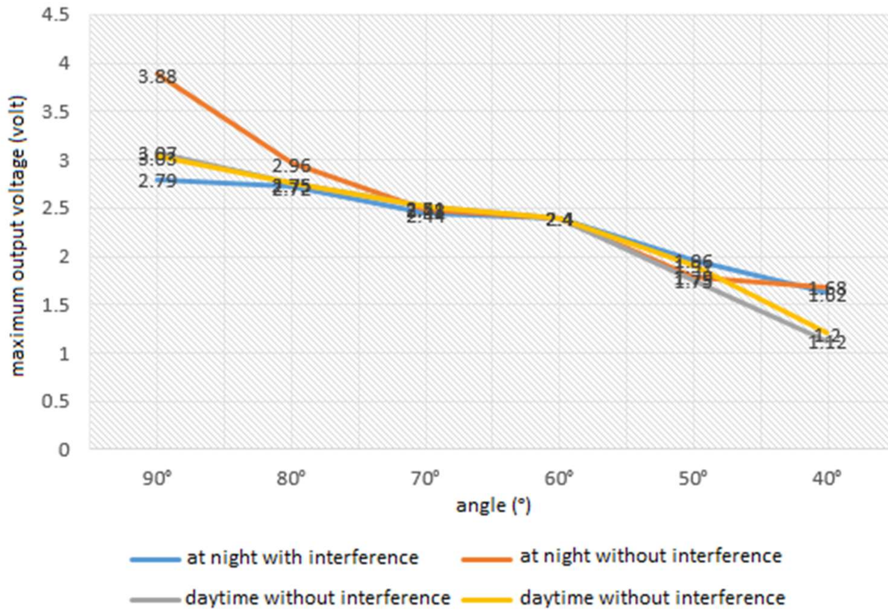


Figure 12. Graph of Angle Measurement Response Against Output Voltage

For output frequency, there is a frequency greater than the input frequency, there is also an output frequency smaller than the input frequency. As for the output voltage is seen that the output voltage decreases the voltage perpendicular to the smaller shrinkage of the measured angle. The magnitude of the output voltage for a 90° angle is 3.07 volts peak to peak and for a 40° angle of 1.12 volts peak to peak.

3.4. Measurement Result with Interference during The Day

The measurements aims to find a good range of angles on the VLC system with a distance between the transmitter and receiver 10 cm apart during the day for the coding in the presence of interference. For output frequency there is a frequency greater than the input frequency, there is also an output frequency smaller than the input frequency. As for the output voltage is seen that the output voltage decreases the voltage perpendicular to the smaller shrinkage of the measured angle. The magnitude of the output voltage for a 90° angle of 3.03 volts peak to peak and for a 40° angle of 1.20 volts peak to peak.

3.5. Measurement Result Without Interference during The Night

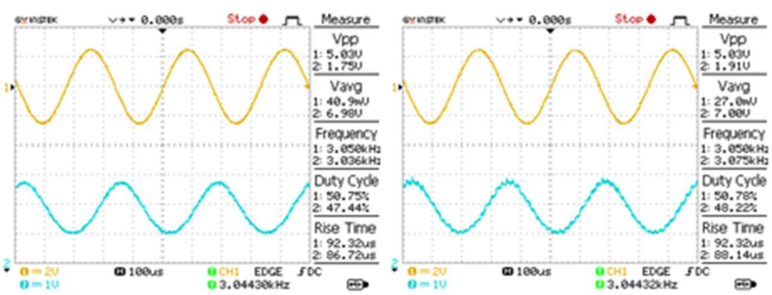
The measurement aims to find a good range of angles on a VLC system with a distance between the transmitter and receiver 10 cm at night with no noise. There is a frequency greater than the input frequency for output frequency, and there is also an output frequency smaller than the input frequency. As for the output voltage is seen that the output voltage decreases the voltage perpendicular to the smaller shrinkage of the measured angle. The magnitude of the output voltage for a 90° angle is 3.88 volts peak to peak and for an angle of 40° at 1.68 volts peak to peak.

3.6. Measurement Result with Interference during The Night

These measurements aim to find a good range of angles on a VLC system with a distance between the transmitter and receiver 10 cm at night with no noise. For output frequency, there is a frequency greater than the input frequency, there is also an output frequency smaller than the input frequency. As for the output voltage is seen that the output voltage decreases the voltage perpendicular to the smaller shrinkage of the measured angle. The magnitude of the output voltage for a 90° angle is 2.79 volts peak to peak and for an angle of 40° at 1.62 volts peak to peak. Results for angles with stable frequency are seen for angles of 60° and the optimal angle is 90°. It can be seen in Figure 12 that the magnitude of the angle is directly proportional to the maximum output voltage. As the angle gets smaller, the maximum output voltage value becomes small. So is the opposite when the angle is greater, then the maximum output voltage value becomes big.

3.7. Measurement result for angle 50º in the day and night

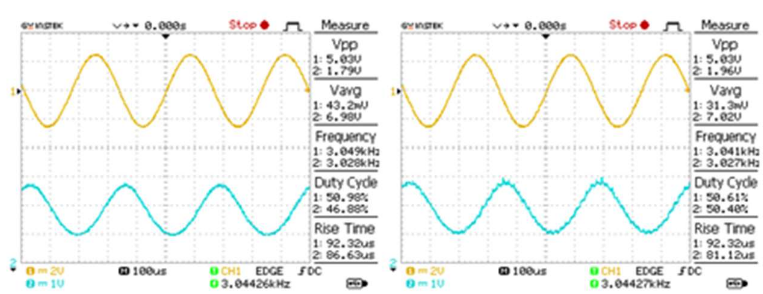
Figure 13 is the result data from system measurement based on angle and environmental conditions. For environmental conditions at the time of measurement conducted during the day.



(a) **(b)**

Fig. 13. (a) Data Result Without Interference During the Day For Angle 50º (b) Data Result With Interference During The Day For Angle 50º

Figure 14 is the result data from system measurement based on angle and environmental conditions. For environmental conditions at the time of measurement conducted at night.



(a) **(b)**

Fig. 14. (a) Data Result Without Interference During the Night For Angle 50º (b) Data Result With Interference During The Night For Angle 50º

The data result for the measurement based on the angle in environmental conditions when daytime and night shows that the output voltage output data in the presence of interference is greater than the output voltage output data without any interference only for the angle of 50º. The measurement results are shown in Figure 13 and Figure 14. The result indicates that the presence of a voltage interruption being increased due to the amplification of the incoming noise rays in the photodiode when the lower blind stick is positioned at an angle of 50º.

4. CONCLUSION

This research implemented the outdoor navigation system for visually impaired persons using visible light communication. The results showed the system of VLC that has been designed and implemented to work well for the human voice frequency range is a frequency of 3000 Hz in the air. It showed the VLC system measurement based on the maximum distance range of the VLC transmitter's sensitivity with the VLC receiver is 10 cm, and angle and environmental conditions can work well is a measuring angle of 90º, environmental conditions at night without any interference. It was obtained for the output voltage value of 3.88 volts peak to peak. System measurement based on angle and when measurement for angle equal to 50º obtained result data indicates that in the presence of disturbance, the output voltage becomes a special increase for angle 50º. The measurement results of daytime conditions without interference are 1.75 volts and with interference is 1.91 volts. The measurement results at night conditions without interference is 1.79 volts and with interference is 1.96 volts.

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