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Light follower systems for visually impaired using visible light communication

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ABSTRACT

Visual impairment is the condition of someone who has a disorder or an obstacle in their vision. In this research, the implementation of light follower systems for visually impaired using visible light is proposed. This system can enable visually impaired people to determine orientation and support mobility, especially in an indoor situation, using visible light. The prototype of the visually impaired pathway was made as visible light communication (VLC) transmitter consisting of a 12 V power supply, light emitting diode (LED), MPEG-1 Layer-3 (MP3), and band pass filter (BPF) filter circuit. The VLC receiver is made a prototype of a blind stick consisting of a photodiode, amplifier, buzzer, timer, and 9 V battery. The measurement of this system uses acrylic and color filters with system accuracy taking into account the angle and conditions when the fluorescent lights are turned on and off. This result showed the system could transmit audio signals at a frequency of 3000 Hz. Furthermore, the comparison results showed that the quality of measurements without using a filter is better than using a filter. The output voltage value without using a filter with an angle of 700 degree is 7.19 Vp-p, meanwhile using a filter with an angle of 700 degree is 6.48 Vp-p.

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1. INTRODUCTION

Visually Impaired are individuals who have difficulty in vision. The definition of visually impaired, according to Hallahan *et al.* [1], is someone who has an insight weakness with an accuracy of less than 6/60. Based on the ability of vision, blind protection is divided into two, namely the total blind and who still have a residual vision. For people with visual impairments in the category of the total blind, the learning process, determine orientation and mobility mostly depend on other sense organs, the sense of touch, and the sense of hearing. On the other side, someone who has low vision can still rely on limited vision abilities, and the ability to be still able to see the light. At this time, visually Impaired are helped by folding sticks that determine orientation and support mobility. The inaccuracy of this device is a challenge for visually impaired, who are specifically designed for indoor activities where items are placed in the area. Therefore, a technology-based system is needed that is developed as a solution. Currently, there are several studies and products developed based on certain technologies that enable the blind to determine orientation and support mobility, especially indoors.

Some research implemented the system that is utilized visually impaired people to identify an object, such as Abdurrasyid *et al.* [2]. This research develops a tool for a blind person who is able to recognize what object in front of him/her when he/she is walking. An attached camera will obtain an image of an object which is then processed using a template matching method to identify and trace the image of the object. After getting the image of the object, furthermore, calculate and compare it with the data training. The output is produced in the form of sound that in accordance with the object. The result of this research is that the best slope and distance for the template matching method to properly detect silent objects is 90 degrees and 2 meters. Another research from Siswono [3] implements glasses that give information in the form of voices through an earphone if there is an obstacle in the range of 0-58 cm. The device is using PING ultrasonic sensor, ATMEGA8535 microcontroller, and ISD25120 for recording and saving the voices. The device will give eight different kinds of voices through the earphone.

For the total blind and residual vision people, visible light can be used to determine orientation path and mobility in indoors utilize visible light communication (VLC) System. In 2015, a study conducted by Ma'ruf *et al.* [4] tried to send an audio signal by utilizing a visible light communication system. Based on the results of the study, audio signals can be sent with a maximum distance that is limited to 20 cm. Previously in 2016, there was a study conducted by Darlis, *et al.* [5]. The research light emitting diode (LED) was by trying to send a video signal with using VLC. The results show that the video signal can be sent from the transmitter to the receiver at various distances using bidirectional methods. Whereas in 2014, research conducted by Kumar and Lourenco [6] tried to implement VLC on traffic signs on the highway. The results of this study indicate that VLC can be applied on the road and send information with a maximum distance of 1.5 m. In 2015, a study conducted by Azka *et al.* [7] tried to transmit digital data in the form of files using the VLC system, this tool can communicate at a maximum distance of 30 cm between the transmitter and receiver at an angle of 0° and a range of 10 cm without interference from other objects. Other researches were done by Fuada *et al.* [8], Deepa *et al.* [9], and Qasin *et al.* [10] that analyze VLC technology that will be used for those systems. Besides that, this technology has been implemented and applied indoors [11-18], underwater [19-23], vehicular [24], and internet network [25].

Based on the previous researches, it can be predicted that the VLC technology allows them to be implemented on a folding stick that is used visually impaired in determining orientation and mobility. In this research, the implementation of light follower systems for visually impaired using visible light is proposed. This system can enable visually impaired people to determine orientation and support mobility, especially indoors, using visible light. The visually impaired pathway as a light follower system path in Indoor was made as a VLC transmitter. The VLC receiver that was equipped with an alarm system is made in a visually impaired folding stick. Utilizing this system, visually impaired can be guided using the audio system utilizing visible light. The measurement of this system uses acrylic and red, green, blue filters with considering measurement based on the angle and the fluorescent lights conditions.

2. DESIGN AND IMPLEMENTATION

2.1. System design

This research discusses how the VLC system works, and the series of this research is shown in Figure 1. In the VLC block transmitter section can be seen the process of an information signal so that it can be transmitted. Input signal when testing using an audio generator in the form of an analog signal is passed through the signal conditioner and then through the white LED before being transmitted where the white LED is given a voltage of 12 V. The light sent by the white LED contains information and is received by the photodiode on the VLC receiver with a white VLC receiver voltage of 9 V. The photodiode functions as a light-receiving sensor and stores the received light energy and converts it into an electrical signal, then enters the amplifier as a signal amplifier and is passed on to the signal conditioner so that it produces the desired output. Light dependant resistor (LDR) functions as a light receiver sensor, to set the alarm system on the VLC receiver will then enter the timer circuit, where the timer circuit will respond to the light received by the LDR, the output produced in the form of an alarm sound on the buzzer.

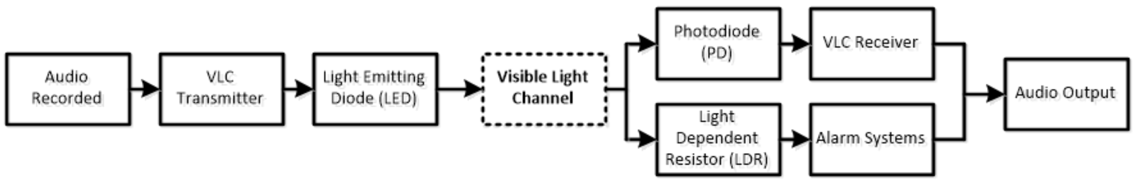
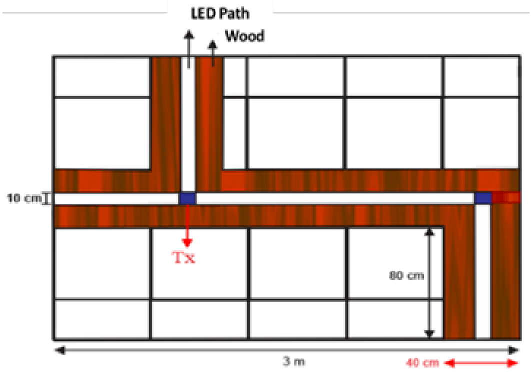


Figure 1. Circuit system block

2.2. Prototype design

The wood material is used to make the prototype VLC transmitter. The LEDs are installed along with the prototype VLC transmitter while the VLC transmitter is installed at every bend on the prototype, meanwhile, the base color acrylic will be installed above to cover the LED mounting path. The VLC transmitter design is shown in Figure 2. The visually impaired stick used is a type of named stick that can be folded and has a length of 120 cm. The VLC receiver is installed in a box that is connected to the visually impaired rod, while the castor wheels are mounted on the stick to facilitate the visually impaired in carrying out this tool. The design of the visually impaired stick is shown in Figure 3.



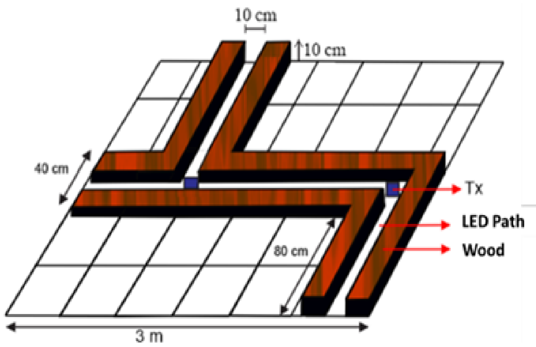


Figure 2. VLC transmitter prototype

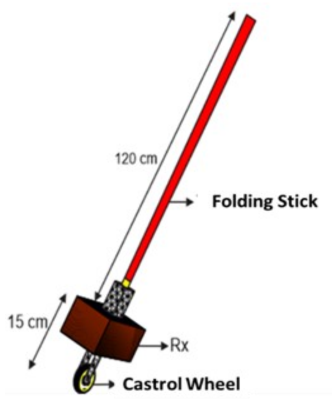
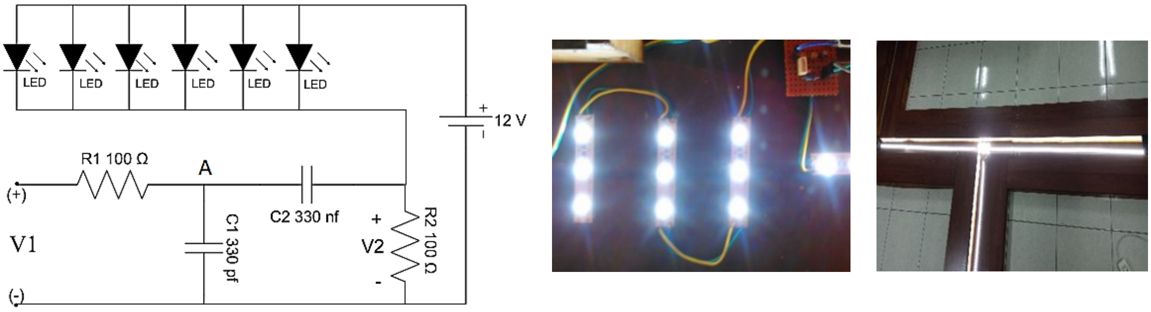


Figure 3. The prototype design of blind stick as VLC receiver

2.3. Prototype implementation

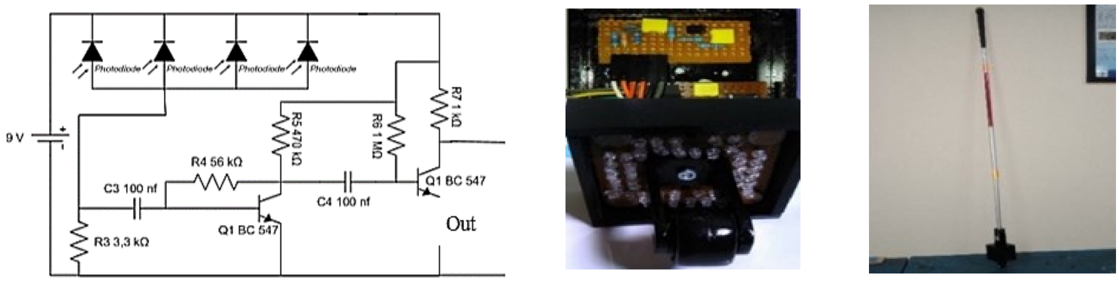
The VLC Transmitter circuit aims to send information signals emitted through LEDs in the form of visible light. The input signal used in this circuit comes from an audio generator with a frequency of 3 kHz. The VLC transmitter circuit is given a voltage of 12 V, while for filtering unwanted signals, the input signal from the audio generator will pass through the bandpass filter before being transmitted through the light with a white LED. The input signal transmitted by the VLC transmitter can be seen using an oscilloscope. The circuit and implementation of the VLC transmitter are shown in Figure 4.

VLC Receiver circuit is intended to receive information signals emitted from the VLC transmitter through the white LED in the form of visible light. VLC receiver circuit consists of several electronic components such as photodiode and amplifier circuit, the information signal sent by the transmitter will be received by the photodiode on the VLC receiver. The photodiode in this circuit functions as a light-receiving sensor and stores the received light energy, and converts it into an electrical signal, then enters the amplifier circuit as a signal amplifier. The output signal received by the receiver can be seen using an oscilloscope. The VLC receiver circuit can receive signals well using a voltage of 9 V. The circuit and implementation of the VLC receiver is shown in Figure 5.



(a) (b) (c)

Figure 4. (a) VLC transmitter circuit [5], (b) Circuit implementation, (c) Path implementation

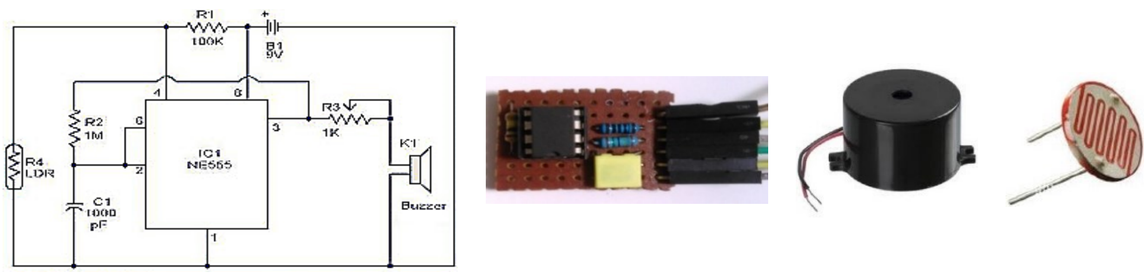


(a) (b) (c)

Figure 5. (a) VLC receiver circuit [5], (b) Circuit implementation, (c) Stick implementation

2.4. Alarm system implementation

This alarm system circuit serves to detect light so that the blind can follow the path in the supermarket properly. This circuit is installed on the VLC receiver. When the alarm is turned on with a voltage of 9 V, the LDR will detect the received light. If the light falls on the LDR, the resistance of the LDR will decrease so that the buzzer will not sound. When the LDR does not receive light, the resistance of the LDR will increase, causing the buzzer to sound. The series and implementation of the alarm system is shown in Figure 6.



(a) (b) (c) (d)

Figure 6. (a) Alarm system circuit, (b) Alarm circuit implementation, (c) Buzzer Lf - MB26, (d) LDR Orp 12

2.5. VLC transmitter and receiver integration

After implementing the VLC transmitter and VLC receiver, the next step is to integrate the VLC transmitter and VLC receiver, as shown in Figure 7. Figure 7 shows the integration of the VLC transmitter with the VLC receiver using red acrylic. The visually impaired stick as a receiver will receive an information signal from the VLC transmitter mounted on the red line at the crossing point. The information sent is in the form of an audio sound recording installed on an MP3 player. Nevertheless, in the present research, the information sent is in the form of an information signal coming from the audio generator. Information received by the visually impaired stick as a receiver is in the form of audio sound recordings that can be listened to by the blind using a headset. While the information signal from the audio generator that is received by the visually impaired stick as a receiver at the time of the study can be seen on the oscilloscope, the alarm system installed on the VLC receiver will make an alarm sound when the visually impaired stick exits the red acrylic path, indicating that the visually impaired person exits the specified way. Whereas if the visually impaired stick is on the right track by following the red acrylic path, the alarm system will not emit an alarm sound.

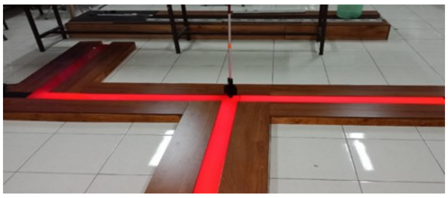


Figure 7. VLC transmitter dan VLC receiver integration

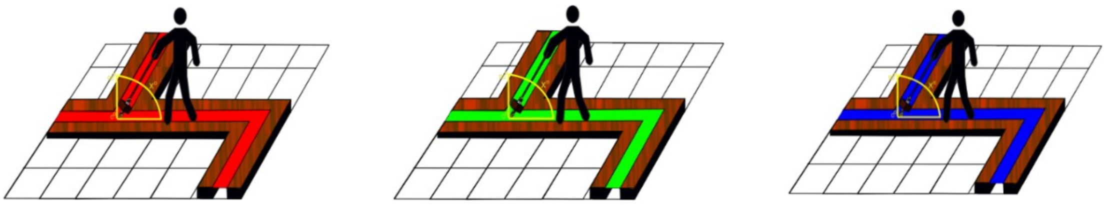
3. RESULTS AND ANALYSIS

After implementing the systems, the next step is to measure and retrieve data from the system. Measuring and data retrieval is carried out, aiming to obtain data that can be compared to determine the performance of the systems that have been made. The measurement method is done considering system angle, use the filter, frequency both without and using neon lights.

3.1. Angle based measurement without the effect of neon lights

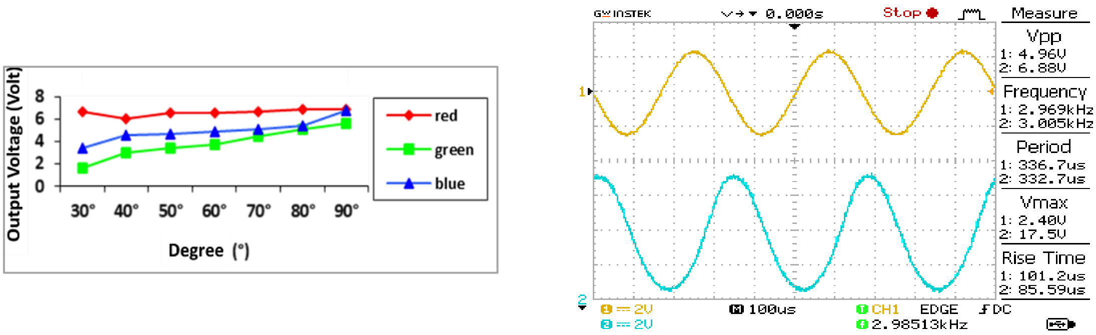
This measurement aims to determine the reliability of the system in sending and receiving audio signals in supermarkets. A signal with a frequency of 3 kHz is generated by using an audio generator, and the reference voltage applied is 5 Vp-p. This measurement used acrylic red, green, blue with angles of 30-90^0. Measurements are taken during the day in room conditions without fluorescent lighting, as illustrated in Figure 8.

From the graph in Figure 9 (a), the results of measurements in this system show that red acrylic measurements are better than green and blue acrylic. This is because the type of photodiode with type SFH 203 has good sensitivity to red color with a wavelength of 620-750 nm. The shape of the signal from measurements using red acrylic with an angle of 90^0 is shown in Figure 9 (b). It shows the signal has the same shape between the signal transmitted and received without a noise with the signal shifting.



(a) (b) (c)

Figure 8. Prototype measurement without the effect of neon lights using; (a) red acrylic, (b) green acrylic, (c) blue acrylic

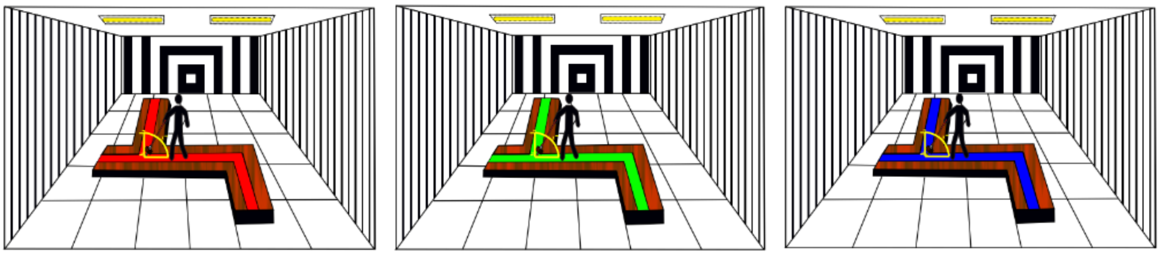


(a) (b)

Figure 9. Measurement results without effects of neon lights; (a) using red, green, blue acrylic, (b) signal shape using 90^0 red acrylic angles

3.2. Angle based measurement with effects of neon lights

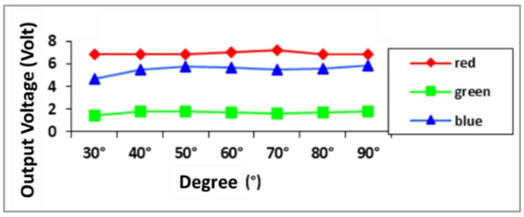
This measurement aims to determine the effect of fluorescent lights in a room, especially in supermarkets, on the reliability of the system in sending and receiving signals at a frequency of 3 kHz. At the same time, the reference voltage used is 5 Vp-p set on the audio generator. This measurement used acrylic red, green, blue with angles of 30-90^0. This measurement is carried out at night in a room with fluorescent light, as illustrated in Figure 10.

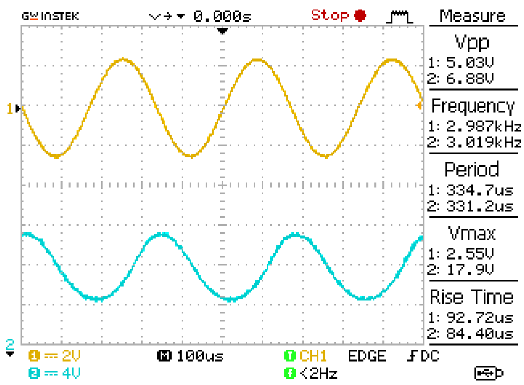


(a) (b) (c)

Figure 10. The prototype of measurement by effect of neon lights using;
(a) red acrylic, (b) green acrylic, (c) blue acrylic

Based on the graph in Figure 11 (a), the results of measurements on this system show that the quality of red acrylic is better than green and blue acrylic. This is due to the influence of fluorescent lamps, and the type of photodiode used is SFH 203. Photodiode with SFH 203 has good sensitivity to red color with a wavelength of 620-750 nm. The shape of the signal from measurements using red acrylic with the influence of fluorescent lights at an angle of 90^0 is shown in Figure 11 (b). The figure shows the signal has attenuation in the signal output. However, the same shape is shown between the signal transmitted and received without noise. From the results of measurements using acrylic, a graph can be made to compare the quality of measurements without the influence of fluorescent lamps in Figure 9 (a), and measurements with the impact of neon lights in Figure 11 (a) by taking references using red acrylic is shown in Figure 12.





(a) (b)

Figure 11. (a) Measurement chart using red, green, blue acrylic with effect of neon lights,
(b) Shape of measurement signal using acrylic red 90^0 with effect of neon lights

From the graph, in Figure 12, the results of measurements in this system show the quality of measurements with the influence of fluorescent lamps is better than measurements without the influence of fluorescent lamps. Based on Figure 12, it can be seen that the measurement with effect fluorescent lamp produces 7.19 Vp-p at the angle 70^0, meanwhile without effect fluorescent produces 6.71 Vp-p at the angle 70^{0}C. This condition happened is due to the impact of fluorescent lamps on this measurement can increase voltage strengthening.

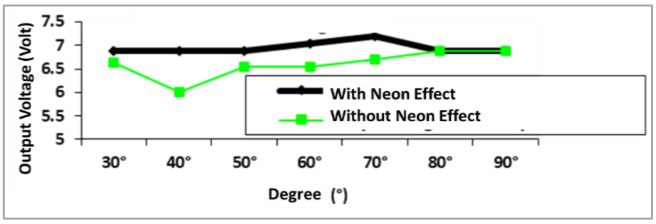


Figure 12. Measurement charts with effects of neon lights and without effects of neon lights

3.3. Measurement using filters without the influence of neon lights

This measurement aims to determine the reliability of the system in sending and receiving signals at a frequency of 3 kHz, while the reference voltage used is 5 Vp-p. This measurement used filters and acrylic red, green, blue with angles of 30-90^0. This measurement is carried out during the day in a room with the neon lights turned off. Figure 13 shows the use of red, green, blue filters installed on the VLC receiver. From the results of measurements without the influence of fluorescent lamps using red, green, and blue filters, a graph can be made to compare the quality of a good filter for this system by using the red acrylic measurement as a reference is shown in Figure 14.

The results of measurements on this system show the quality of the red filter is better than the filter green and blue. We have seen from Figure 15 the red filter with 90^0 angles of 6.32 Vp-p and the green filter with 90^0 angles of 3.20 Vp-p while the blue filter with 90^0 angles of 5.19 Vp-p. This is because the type of photodiode used is SFH 203. Photodiode with SFH 203 has good sensitivity to red color with a wavelength of 620-750 nm. The shape of the signal from measurements using a red filter without the influence of fluorescent lights at an angle of 90^0 is seen in Figure 15. It has shown the signal have amplification from the transmitted signal without external interference.

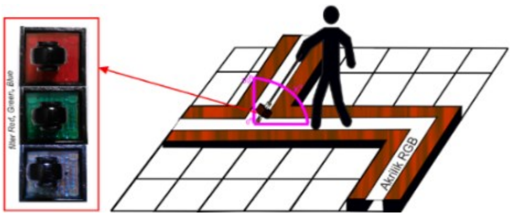


Figure 13. Measurement without the effect of using neon lights filter red, green, blue

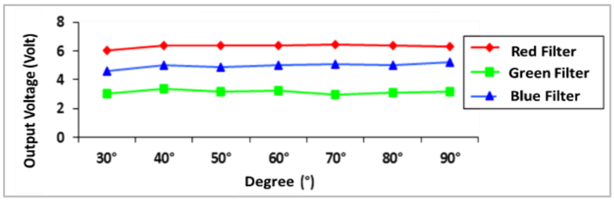


Figure 14. Measurement chart using red, green, blue filters without the effect of neon lights

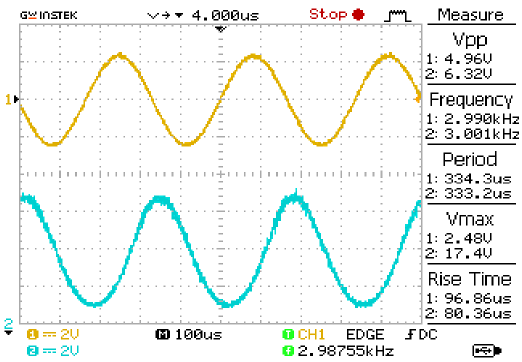


Figure 15. Measurement signals using red filters with 90^0 angle without the effect of neon lights

3.4. Measurement using a filter with the effect of neon lights

This measurement aims to determine the reliability of the system in sending and receiving signals using red, green, and blue filters with the influence of fluorescent lamps at a frequency of 3 kHz. In contrast, the reference voltage applied is 5 Vp-p. This measurement used filters and acrylic red, green, blue with angles of 30-90^0. This measurement is carried out on even days in a room with fluorescent light. Figure 16 shows the use of red, green, blue filters installed on VLC receivers with the influence of fluorescent lamps.

Based on the measurement results using red, green, and blue filters with the influence of fluorescent lights, a graph can be made to compare the quality of an excellent base color filter for this system by using the red acrylic measurement as a reference as shown in Figure 17. In Figure 17, it can be found that the quality of the red filter is better than the green and blue filters. It can be seen that based on Figure 17, red filter with 90^0 angles of 6.40 Vp-p and green filter with 90^0 angles of 3.11 Vp-p while the blue filter with 90^0 angles of 5.19 Vp-p. This is because the type of photodiode used is SFH 203. Photodiode with SFH 203 has a good sensitivity to red color with a wavelength of 620-750 nm. The shape of the signal from measurements using a red filter with the influence of neon light at an angle of 90^0 is shown in Figure 18. From the results of measurements, using a primary color filter can be made a graph to compare the quality of measurements without the influence of fluorescent lamps in Figure 19 and measurements with the impact of neon lights in Figure 17 by taking references using the red filter is shown in Figure 19.

The results of measurements in this system show the quality of measurements without the influence of fluorescent lamps is better than measurements with the influence of fluorescent lamps. We have seen from Figure 20 measurements without the influence of fluorescent lamps with an angle of 700 at 6.48 Vp-p and measurements with the effect of neon lights with an angle of 70^0 at 6.15 Vp-p. This is because the impact of using a filter can cause a weakening of the voltage. To compare the best measurement quality without using the filter in Figure 20, a chart can be made by taking the measurement reference using red acrylic and red filter as shown in Figure 21 graph shows the measurement results without using a filter with an angle of 70^0 of 7.19 Vp -p and measurements using a filter with an angle of 70^0 of 6.48 Vp-p. The measurements results in this system show the quality of measurements without using a filter is better than measurements using a filter. This is because the effect of using a filter on this measurement can result in the attenuation of the voltage.

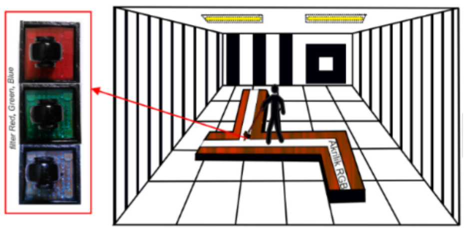


Figure 16. Measurement of the effect of using neon lights filter red, green, blue

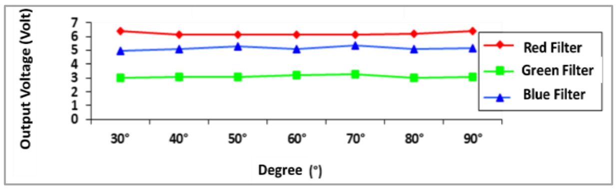


Figure 17. Measurement chart using red, green, blue filters with effect of neon lights

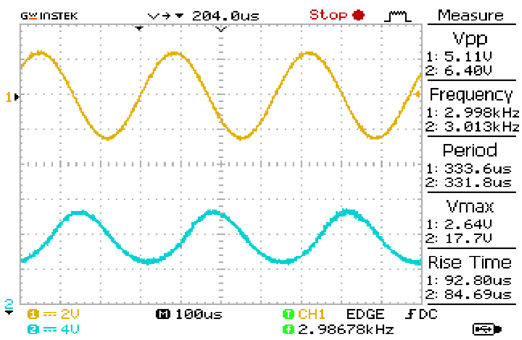


Figure 18. Measurement signals using red filters, with effects of neon lights at 90^0 angle

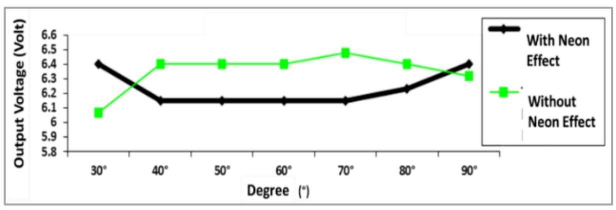


Figure 19. Measurement charts with effects of neon lights and without effects of neon lights using the red filter

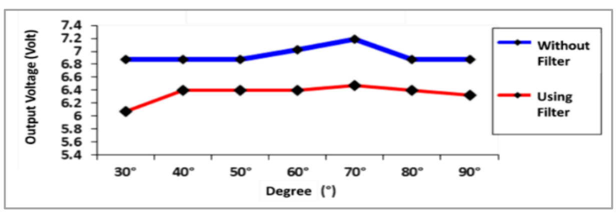
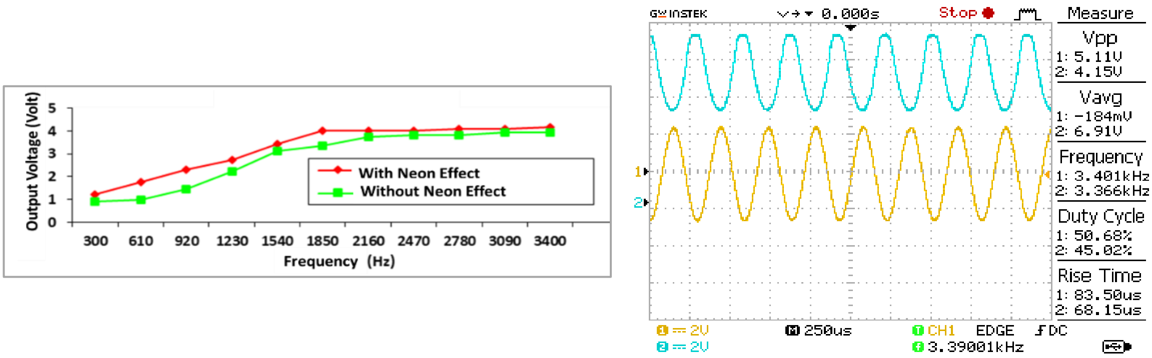


Figure 20. Measurement chart using filters and without using filters

3.5. System measurement based on angle with frequency range

This measurement aims to determine the reliability of the system in sending and receiving signals at frequencies from 300-3400 Hz. Signals with a frequency range of 300-3400 Hz are generated by using an audio generator with a reference voltage of 5 Vp-p. In this measurement, red acrylic with an angle of 90^0 is used as a reference. Figure 21 (a) shows that with a frequency of 300 Hz, the signal can still be sent, but with poor quality, the higher the frequency used, the better the signal transmission. Quality of transmission with the influence of fluorescent lamps with an angle of 90^0 at a maximum frequency of 4.15 Vp-p is better than sending signals without the influence of fluorescent lamps with an angle of 90^0 at a maximum frequency of 3.92 Vp-p. This is because the influence of fluorescent lamps on this measurement can increase the voltage strengthening. The shape of the signal from the measurement using the frequency range with the influence of the neon lamp at an angle of 90^0 is shown in Figure 21 (b). It showed the signal has the same shape between the transmitted and received signal without noise.



(a) (b)

Figure 21. (a) Measurement chart with frequency range,
(b) Signal of frequency range measurement by effect of neon lights

4. CONCLUSION

Based on our worked, it can be found the several conclusion as follow; (a) A designed and implemented VLC transmitter and VLC receiver system can transmit a signal with a sound frequency of 3000 Hz. (b) The results of the comparison between measurements using red, green and blue acrylic without the influence of fluorescent lighting and with the influence of fluorescent lighting show that the quality of measurements with the influence of fluorescent lamps is better than measurements without the influence of fluorescent Lamps, and the voltage ouput with an angle 70^0 is equal with 7.19 Vp-p. (c) The results of the comparison between measurements using filters and acrylic red, green and blue without the influence of fluorescent lighting and with the influence of fluorescent lighting show the quality of measurements without the influence of fluorescent lamps is better than measurements with the influence of fluorescent lamps, and the voltage output with an angle 70^0 is equal with 6.48 Vp-p. (d) The overall comparison results show that the quality of measurements without using a filter is better than the measurement using a filter, the output voltage value without using a filter with an angle of 70^0 is 7.19 Vp-p, and the measurement using a filter with an angle of 70^0 is 6.48 Vp-p.

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REFERE#NCES

[1] Hallahan, D. P., Kauffman, J. M., & Pullen, P. C., "Exceptional learners: An introduction to special education, 13th Edition," *Upper Saddle River, NJ: Pearson,* 2015.
[2] Abdurrasyid A., Indrianto I., & Arianto R., "Detection of immovable objects on visually impaired people walking aids," *TELKOMNIKA Telecommunication Computing Electronics and Control,* vol. 17, no. 2, pp. 580-585, 2018.
[3] Siswono H., "Glasses for the blind using ping ultrasonic," *TELKOMNIKA Telecommunication Computing Electronics and Control,* vol. 18, no. 2, pp. 945-952, 2020.

[4] Ma'ruf M. I., Pramono S. H., and Othman M. B., Visible Light Communication (VLC) System for Audio Transmission," *Jurnal Mahasiswa TEUB*, vol. 3, no. 3, 2015.
[5] Darlis A. R., Lidyawati L., Trikusumo R. J., "Bidirectional Video Visible Light Communication," *Electrotehnica, Electronica, Automatica (EEA),* vol. 68, no. 2, pp. 85-92, 2020.
[6] Kumar N., & Lourenço N. R., "Led-Based Visible Light Communication System: A Brief Survey and Investigation," *Journal of Engineering and Applied Sciences,* vol. 5, pp. 296-307, 2010.
[7] Aska B. F., Darlis D., & Hafiddudin, "Implementation of Visible Light Communication (VLC) for Sending Data Digital," *Prodi D3 Fakultas Ilmu Terapan Universitas Telkom,* 2015.
[8] Fuada S., Putra A. P., Aska Y., & Adiono T., "Noise Analysis of Trans-impedance Amplifier (TIA) in Variety Op Amp for use in Visible Light Communication (VLC) System," *International Journal of Electrical and Computer Engineering,* vol. 8, no. 1, pp. 159-171, 2018.
[9] Deepa T., Mathur H., & Sunitha K. A., "Spectrally efficient multicarrier modulation system for visible light communication," *International Journal of Electrical and Computer Engineering,* vol. 9, no. 2, pp. 1184-1190, 2019.
[10] Qasim A. A., Abdullah M. F. L., Mohammedali H. N., Talib R. Bin, Nemah M. N., & Hammoodi A. T., "Low complexity DCO-FBMC visible light communication system," *International Journal of Electrical and Computer Engineering,* vol. 10, no. 1, pp. 928-934, 2020.
[11] Dahri F. A., Umrani F. A., Baqai A., & Mangrio H. B., "Design and implementation of LED–LED indoor visible light communication system," *Physical Communication,* vol. 38, 2020.
[12] Peng X., & Kong L., "Design and optimization of optical receiving antenna based on compound parabolic concentrator for indoor visible light communication," *Optics Communications*, vol. 464, 2020.
[13] Kizilirmak R. C., "Impact of repeaters on the performance of indoor visible light communications," *Turkish Journal of Electrical Engineering and Computer Sciences,* vol. 23, no. 4, pp. 1159-1172, 2015.
[14] Bandara K., Niroopan P., & Chung Y. H., "Improved indoor visible light communication with PAM and RLS decision feedback equalizer," *IETE Journal of Research,* vol. 59, no. 6, pp. 672-678, 2013.
[15] Rahman M. S., & Kim K. D., "Indoor location estimation using visible light communication and image sensors," *International Journal of Smart Home*, vol. 7, no. 1, pp. 99-114, 2013.
[16] Yi Y., Li C., & Lee K., "Optimum spread code applied in indoor visible light data transmission for optical multipath dispersion reduction," *IETE Technical Review,* vol. 30, no. 3, pp. 233-239, 2013.
[17] Zhang T., Guo S., Chen H., Zhong F., & Ma C., "Enhancing the bit error rate of indoor visible light communication systems using adaptive channel estimation algorithm," *IET Communications,* vol. 9, no. 4, pp. 501-507, 2015.
[18] Rahman M. S., & Kim K., "Indoor Positioning by Led Visible Light Communication and Image Sensors," *Journal of Electrical Engineering and Computer Sciences,* vol. 1, no. 2, pp. 161-170, 2011.
[19] Darlis A. R., Cahyadi W. A., & Chung Y. H., "Shore-To-Undersea Visible Light Communication," *Wireless Personal Communication,* vol. 99, no. 2, pp. 681-694, 2018.
[20] Periasamy C., Vimal K., & Surender D., "Led Lamp Based Visible Light Communication in Underwater Vehicles," *Int. J. Eng. Trends Technol.,* vol. 13, no. 3, pp. 103-106, 2014.
[21] Fickenscher T., Holborn J., & Thiel D. V., "Underwater Wireless Optical Communication for Swimmer Feedback Using Irda Transceiver," *Electron. Lett.,* vol. 47, no. 24, pp. 1335-1336, 2011.
[22] Tian B., Zhang F., & Tan X., "Design and development of an LED-based optical communication system for autonomous underwater robots," *IEEE/ASME International Conference on Advanced Intelligent Mechatronics,* Wollongong. NSW, pp. 1558-1563, 2013.
[23] Darlis A. R., Widura A., & Andrian M. R., "Bidirectional Underwater Visible Light Communication," *International Journal of Electrical and Computer Engineering,* vol. 8, no. 6, pp. 5203-5214, 2018.
[24] Kristiana L., Darlis A. R., Dewi I., "A. The feasibility of obstacle awareness forwarding scheme in a visible light communication vehicular network (VLC-VN)," *International Journal of Electrical and Computer Engineering,* vol. 10, no. 6, pp. 6453-6460, 2020.
[25] Matheus L., Pires L., Vieira A., Vieira L. F. M., Vieira M. A. M., Nacif J. A., "The internet of light: Impact of colors in LED-to-LED visible light communication systems," *Internet Technology Letters,* pp. 1-6, 2019.