A DEVELOPMENT OF SECURE IOT WIRELESS COMMUNICATION SIGNAL USING VISIBLE LIGHT SOURCE FOR SMART HOME.

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DECLARATION

I declare that this report is my original work and all references have been cited adequately as required by the university.

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APPROVAL PAGE

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ABSTRACT

To light up the world of technology, where wireless communication has bloomed to a great extend which requires a lot of data to be transmitted and received every fraction of the second a new era is coming. Electromagnetic waves such as radio waves are the main way to transmit wireless data, but certain limitations are there because radio waves can only support less bandwidth because of compact spectrum availability and intrusions. Visible Light Communication (VLC) has come to take way those issues. The new technology Li-Fi which stands for Light-Fidelity is a new kind of wireless communication system which uses light waves as a medium instead of radio frequency electromagnetic waves. This project presents an eco-friendly data communication system through visible light which consists of LEDs that transmit data to the receiver. According to the received signal, the information of present location at light source and further diversions is displayed on the LCD and speaker installed at the receiver. Thus, this technology provides better way rather than radio waves which could be an alternative choice for smart home projects in future.

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LIST OF ABBREVIATIONS

Abbreviation		Descriptions
CAD	-	Computer-Aided Design
CSI	-	Camera Serial Interface
CSK	-	Colour Shift Keying
D2D	-	Device to Device
DAC	-	Digital-to-Analog Converter
DC	-	Direct Current
DD	-	Direct Detection
DMT	-	Discrete Multi-Tone
DSI	-	Digital Serial Interface
DSP	-	Digital Signal Processor
EM	-	Electromagnetic
FSK	-	Frequency Shift Keying
GHz	-	Gigahertz
GPIO	-	General Purpose Input Output
GSM	-	Global System Mobile
GUI	-	Graphical User Interface
HDMI	-	High Definition Multimedia Interface
IDE	-	Integrated Development Environment
IoT	-	Internet of Things
IP	-	Internet Protocol
IR	-	Infrared
LAN	-	Local Area Network
LCD	-	Liquid Crystal Display
LD	-	Laser Diode
LDR	-	Light Diode Resistor
LED	-	Light Emitting Diode
Li-Fi	-	Light Fidelity

LoS	-	Line of Sight
LPDDR	-	Low Power Double Data Rate
M2M	-	Machine to Machine
MAC	-	Media Access Control
MHz	-	Megahertz
MIPI	-	Mobile Industry Processor Interface
MP3	-	Media Player 3
NC	-	Normally Close
NLOS	-	Non-Light of Sight
NO	-	Normally Open
NOOBS	-	New Out of Box Software
OEM	-	Original Equipment Manufacturing
OFDM	-	Orthogonal Frequency Division Multiplex
OLED	-	Organic Light Emitting Diode
OOK	-	On-Off Keying
OS	-	Operating System
OWC	-	Optical Wireless Communication
PCB	-	Printed Circuit Board
PCM	-	Pulse Code Modulation
PD	-	Photodiode
PHY	-	Physical layer
PIC	-	Programmable Interface Controllers
PLC	-	Programmable Logic Controllers
QAM	-	Quadrature Amplitude Modulation
RF	-	Radio frequency
RGB	-	Red Green Blue
RLL	-	Run Length Limited
RPI	-	Raspberry Pi
SCIPPM	-	Sub-Carrier Inverse Pulse Position Modulation
SD	-	Secure Digital
SDRAM	-	Synchronous Dynamic Random Access Memory
SIMO	-	Single Input Multiple Output
SISO	-	Single Input Single Output

SNR	-	Signal Noise Ratio
TCP	-	Transmission Control Protocol
THz	-	Terahertz
TIA	-	Transimpedance amplifier
USB	-	Universal Serial Bus
UV	-	Ultraviolet
VLAN	-	Virtual Local Area network
VLC	-	Visible Light Communication
Wi-Fi	-	Wireless Fidelity

CHAPTER 1

INTRODUCTION

1.1 Overview

Li-Fi, or "Light Fidelity", refers to wireless communication systems using light from light-emitting diodes as a medium instead of traditional radio frequencies, as in technology using the trademark Wireless Fidelity (Wi-Fi). Li-Fi is expected to be ten times cheaper than Wi-Fi. Li-Fi has the advantage of being able to be used in electromagnetic sensitive areas such as in aircraft and nuclear power plants without causing interference. The light waves cannot penetrate walls which makes a much shorter range, though more secure from hacking, relative to Wi-Fi.

More amounts of data can be sent through light because light waves are having a bandwidth 10,000 times more than radio-waves. Using visible light for communication also reduces the risk of being exposed to radio waves. This Visible Light Communication (VLC) protocol, used for communication can be applicable in places where the radio waves are restricted like, secured military premises, airplanes, in some research area premises, and hospitals.

The general term Visible Light Communication (VLC) includes any use of the visible light portion of the electromagnetic spectrum to transmit information. The term Li-Fi was coined by Harald Haas from the University of Edinburgh in the UK. The D-Light project at Edinburgh's Institute for Digital Communications was funded from January 2010 to January 2012.Haas promoted this technology in his 2011 TED Global talk and helped start a company to market it. Pure VLC is an original equipment manufacturer (OEM) firm set up to commercialize Li-Fi products for integration with existing LED-lighting systems.

In October 2011, companies and industry groups formed the Li-Fi Consortium, to promote high-speed optical wireless systems and to overcome the limited amount of radio-based wireless spectrum available by exploiting a completely different part of the electromagnetic spectrum. Several companies offer unidirectional VLC products.

VLC technology was exhibited in 2012 using Li-Fi. By August 2013, data rates of over 1.6 Gbps were demonstrated over a single-color LED. In September 2013, a press release said that Li-Fi, or VLC systems in general, do not require line-of-sight conditions. In October 2013, it was reported Chinese manufacturers were working on Li-Fi development kits.

VLC communication is modeled after communication protocols established by the IEEE 802 workgroup. This standard defines the physical layer (PHY) and media access control (MAC) layer. The standard can deliver enough data rates to transmit audio, video, and multimedia services. It takes count of the optical transmission mobility, its compatibility with artificial lighting present in infrastructures, the defiance which may be caused by interference generated by the ambient lighting. The MAC layer allows to use the link with the other layers like the TCP/IP protocol.

1.2 Common applications on Li-Fi

The capacity of radio waves is expensive, less bandwidth, insufficient spectrum and availability of these radio waves is limited. These radio waves are not available in aircrafts or in hospitals. The technology is congested due to the high usage of 2G,3G,4G. The base stations used are only 5% efficient .95% of the efficiency is used in cooling the base stations. the security is also suffered. The Wi-Fi is penetrable through the wall. Security is the big issue as unauthorized person can access the private matters and less economic system. Availability of radio waves is less hence tariff rates are high. Due to this it is highly expensive. Moreover, radio waves cannot pass under sea.

These drawbacks gave rise to find an invention and a new method of communication that is visible light communication. This technology is yet to come in the market that is based on data communication through light.

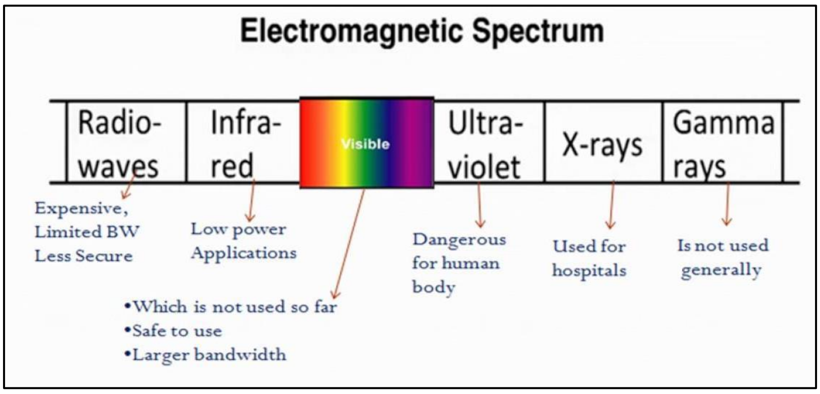

Figure 1.1: Electromagnetic Spectrum and Visible Light portion (Amitoj Singh 2017).

Figure 2.2: Visible Light workaround concept model (Amitoj Singh 2017).

1.3 Problem Statement

Li-Fi is wireless communication, which is an improvised technology of Wi-Fi, but it is different in every aspect such as data transmission rates, security, high frequency and bandwidth. In an era of globalisation where people were surrounded by wireless technologies around them like smartphones and cellular towers.

However, current technology has its own drawbacks which leads to this new technology. As issues that have been viewed, radio frequency such as Wi-Fi tends to have lot of noise and interface when crowded frequency bands available. This can be determined by signal to noise ratio (SNR) in common communications system applications throughout the signals.

Nowadays, everyone wants most of the things based on wireless technologies including the use of radio waves for communication like Bluetooth & Wi-Fi and the new emerging technology Li-Fi. The Li-Fi technology uses LEDs for data transmission. Li-Fi is rapidly growing and taking a place in the market as the technology is fast and secure compared to other wireless technologies and can transmit the data at a very high speed. Li-Fi offers better connection in short range by suitable methods of applications especially indoor usage.

Since Li-Fi known to be a short-range communication system, this technology known as secured signal compared to other radio waves spectrum. By being only blocked by opaque material, this technology could deliver only specific range of data access by single input single output (SISO) or single input many outputs (SIMO). Basically, indoor radio frequency spreads with medium range capability signal but when some of the radius were left unusable, it will lead to potential unsecured communications from anyone.

By integrating Li-Fi systems into IoT capabilities, this will lead to a new smart home idea on the communication system works. Many researchers did not implement IOT capabilities as this is a new outcome to the communication system. IOT is one of the main paths of Industrial Revolution 4.0 by bringing technology to the hardware systems. Thus, by integrating Li-Fi system with IOT could expand the usage of IR 4.0 ideas on the next level of products.

1.4 Objectives

The main objective of this research and project is to enhance and improve the idea of visible light communication by integrating IoT elements in a smart home application. In order to achieve the main objectives, some sub-objective of the research can be developed.

1. To study alternative or innovation of frequency spectrum through communication system using "Visible Light Communication / Li-Fi" and its suitable applications.
2. To develop a secure wireless communication by separating different output or channel with single source.
3. To design a smart home based with VLC - IoT compatible model by monitoring the condition of LED or bulb

1.5 Scopes of Project

This project will focus on innovation on Li-Fi system by integrating IoT capability to smart homes. The Li-Fi system were prepared on an electronic simulation board on designing the prototype model by using Proteus and Tinkercad. This early design can visualize the progress of the prototype circuit by testing best choice of component before the real circuit were built on. The main component of this project requires a light source transmitter and a light detector receiver as the medium for transferring data by using visible light source. The output of the project will be testing about single channel output or multiple output on various type of transmitter by using bulb, LED or laser driver.

A model of smart home will be design as a visual prototype to demonstrate real view of product works and a software simulated project to reach the objectives of this study. This idea will be integrated with IoT capability which can monitoring the status of light source.

1.6 Limitation of Project

However, not all appliances will implement this technology as Li-fi system is visible by the line of sight which only transmit data when there is a light. By using visible light, the data transmission could be blocked by an opaque material rather than other electromagnetic waves such as wi-fi technology. By designing this system, the flickering of the light source could be seen as the data transmitted to the receiver. Somehow, some other researchers say that the flickering of light source could be undetectable by the human eyes as the technology occurs in a microseconds blink of process. Several of other project purposed by the other researchers about visible light communication to analyze the significant findings related to the idea based on the following scenarios:

Project 1: Visible Light Communication using Solar Panel
Project 2: Realtime Audio streaming using Visible Light Communication
Project 3: Simplified integration of power line and Visible Light Communication
Project 4: Image transmission using Li-Fi
Project 5: Prototyping of a Li-Fi communication system
Project 6: Design of RGB Laser Diode drivers for Smart Lighting and Li-Fi using MATLAB GUI.
Project 7: Highway navigation system using Light Fidelity technology
Project 8: Patient monitoring in the hospital management using Li-Fi
Project 9: Method for calculating the energy loss of a light signal in a telecommunication Li-Fi system

1.7 Significance of Project

This idea of project is to acquire alternative ways of electromagnetic spectrum to expand the research of communication system field. By reaching visible spectrum of light, there is an expanding idea regarding this innovation as there were not used yet so far nowadays. An IoT capabilities was added to provide better purpose setup as it was combined for lighting system and data transmitter. Thus, this idea gives a compact system rather than standard Wi-Fi system recently used in smart homes. By implementing these projects has a very wide scope in near future as it could help to setup outdoor system as well as indoor application in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter has discussed about general information on how fast the growth of technology and the importance of Internet of Things (IoT) has utilize Light Fidelity (Li-Fi) or Visible Light Communications (VLC) in wireless communications. This technology over the last decade propose an idea for the researchers to consider the light as an alternative source data transmission instead of radio waves. Since Industrial Revolution 4.0 has been a part of this globalization, immense attention of the concept integration in Internet of Things (IoT) will lead to a new level of this communication works. A brief comparison between journals regarding Visible Light Communications (VLC) would also be conducted to provide some insight for the topic.

2.2 Industry 4.0 Insights

According to four industrial revolutions so far, the first industrial revolution was the invention of energy generation methods using steam and water led to the industrial transformation with trains and improvisation of manufacturing. The second industrial revolution was the period where electricity was invented, which enhanced manufacturing with new inventions, such as the assembly lines. This revolution was directed to high productivity with some extent of automation. The third industrial revolution was obviously the birth of the Internet. Computerization, networking, robotics, and connectivity were the significant transformation in a way information is handled and shared with far more automation. Fourth industrial revolution (Industry 4.0) is a shift from the Internet and the client-server model to ubiquitous mobility with additional accelerators such as advanced robotics and artificial intelligence. This revolution enables automation and optimization with entirely new ways that lead to fully automated systems (i SCOOP. Industry 4.0: the fourth industrial revolution, 2019).

In general, the primary purpose of Industry 4.0 is the emergence of digital estate, also named as “smart home”, which means smart networking, mobility, interoperability, flexibility in household works and wellbeing. Out of which the main focus of this work is to enhance interoperability, decentralization and modularity. The modularity deals with the replacement and expansion of the modules and systems as per the changing need, flexibility and dynamic environment. Interoperability and interconnections mainly focus on standard protocols and Internet of Things (IoT). The decentralization and autonomous decisions contribute new innovative ideas in new smart home ideas.

2.3 Visible Light Communication principles and Li-Fi.

In the last decade, the world have seen a dramatic increase in the traffic carried by the telecommunication networks, with the mobile traffic representing one of the main contributor The last forecasts indicate that the total mobile data traffic is expected to rise at a compound annual growth rate of 42% and the monthly global traffic will surpass 100EB in 2023 based on Mobile data traffic growth outlook (Ericsson) in 2017. These numbers are mainly due to the desire of human beings to communicate from anywhere at any time, and it has been satisfied by the wireless technologies. Wireless devices, applications and services have become very pervasive in our life, changing it radically. Therefore, in order to keep the pace with this growing demand, it has been defined a new set of standards for the wireless and wire communications, the 5G (fifth generation) (J. G Andrews et al., 2015). With the term wireless communication, people usually refer to technologies that use radio waves to transfer information between two or more points without using a wire (electrical conductor). In fact, the Radio Frequency (RF) band, that lies between 30 kHz and 300 GHz of the Electromagnetic (EM) spectrum, has been the most used portion for communication purposes, mainly due to little interference in the frequency band and wide area coverage. However, the RF is just a part of the EM spectrum, as shown in Figure 2.1. This can be seen that includes Infrared (IR), Visible and Ultraviolet (UV) light and these wavelengths are used in the Optical wireless communications (OWC) as unguided lights carrying a signal.

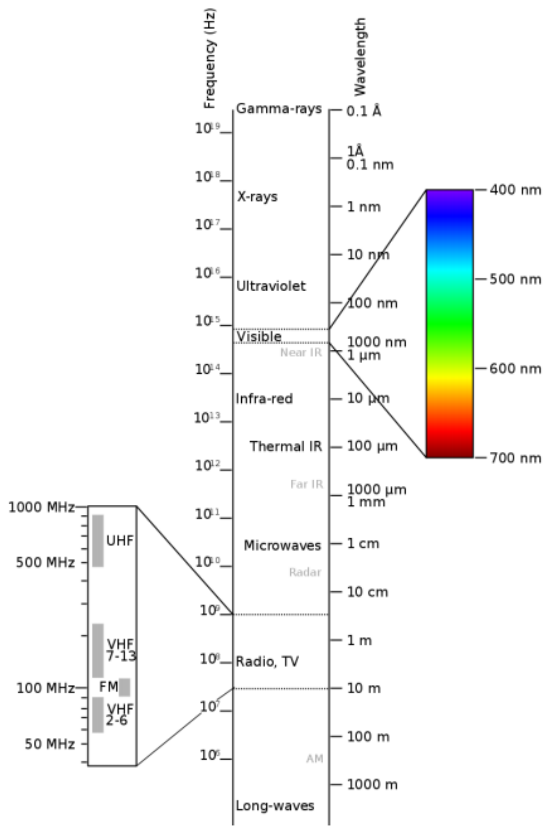

Figure 2.1: Electromagnetic spectrum frequency and wavelength. (J. G Andrews et al., 2015).

OWC is a complementary technology to RF and it offers opportunities that are still mostly unexploited so far. In comparison to the RF counterparts. OWC shows greater features such as ultra-high bandwidth, robustness to electromagnetic interference, a high degree of spatial confinement bringing virtually unlimited frequency or wavelength reuse, and inherent physical security. In addition, since OWC technologies can operate in the unregulated spectrum, OWC provides cost effectiveness for several applications because no licensing fee is required (Xiaona Liu, Chen Gong, Zhengyuan Xu, 2017). When an OWC system uses the wavelengths from 390 to 700 nm based on Figure 2.2, this refer to as a Visible Light Communication (VLC). The peculiarity of this part performance on Visible Light Communication technology electromagnetic spectrum is to have waves with the ability of activate photoreceptor in the human cornea.

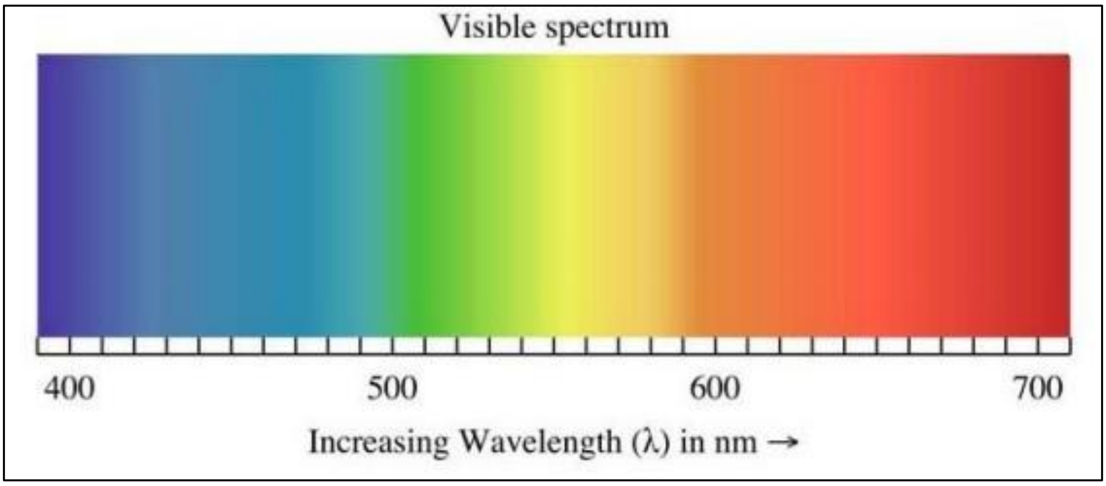

Figure 2.2: Electromagnetic Spectrum that visible to human eyes (Xiaona Liu, Chen Gong, Zhengyuan Xu, 2017).

VLC exploits solid-state lighting such as LEDs for data communication, modulating and transmitting a data stream by varying the intensity of luminaires. In other words, an LED can serve as a dual-purpose device, offering lighting and communication simultaneously, providing a viable solution to alleviating the spectrum shortage in the RF band (Mithileysh Sathiyanarayanan, Vignesh Govindraj, Nandakishor Jahagirdar, 2017).

There are several benefits to implementing VLC, among which (V. W. S. Wong, R. Schober, D. W. K. Ng, and L.-C. Wang, Eds., 2017):

1. VLC systems facilitate simple co-channel interference management and offer a high level of communication security. In indoor scenarios, the signals from VLC systems are confined by the walls of rooms, preventing interference by VLC systems in other rooms and potential eavesdropping.

2. VLC is energy efficient. Traditional indoor lighting or illumination is ubiquitous in the modern world. Since in the last years the environment health and safety has become an important topic, governments around the world are encouraging the replacement of energy-inefficient halogen lamps and incandescent lamps with energy efficient LEDs. This trend is paving the way for the development of ubiquitous VLC systems as LED illumination begins to spread widely. Furthermore, the energy used for communication in VLC is essentially free, as lighting is required anyway. VLC not only has the potential to offer higher data rates but also has various important applications in the IoT, intelligent transportation systems, indoor positioning, and entertainment.

For the realization of truly mobile communication systems, a complete networking solution is required, which leads to the concept of Light-Fidelity (Li-Fi), antilogous to Wi-Fi. Li-Fi is a subset of VLC that exhibits high-speed, bidirectional, fully networked communications. The term was introduced the first time by Professor Harald Haas in Wireless Data from every light bulb, TED Talks in 2011. For instance, in order to achieve communication with multiple VLC receivers in an indoor environment, a cellular network structure composed of several small optical attocells has been proposed (Hanaa Abumarshoud, Hamada Alshaer, Harald Haas, 2019).The goal is to provide seamless coverage and high spectral efficiency to multiple users simultaneously. In practice, an optical attocell network can be realized by installing multiple Li-Fi access points in the ceiling of a room. The VLC system architecture, together with the channel model and the modulation schemes will be now introduced.

2.4 Visible Light Communication system

The main components of the system are the transmitter (lighting source), the optical wireless channel and the receiver (the photodetector). More in the details, the transmitter consists of a Digital Signal Processor (DSP) with a Digital-to-Analog Converter (DAC), which supply for the modulation of the digital information bits and their transformation into an analog current signal. This current signal, that carries the information, drives the optical emitter (i.e. an LED or an array of LEDs) and it is transformed into optical intensity. The optical signal can be passed through an optical system to further shape the transmitted beam. Here, an optical amplifier lens, a collimator, or a diffusor can be employed to concentrate or broaden the beam.

The optical signal is then transmitted over the optical wireless channel. A portion of the optical energy is absorbed by the objects in the environment, and the rest is reflected back in a diffuse or specular manner. Directed and reflected signal components arrive at the receiver. An optical filter is applied to reduce the interference from ambient light and, optionally, to select a portion of interest in the optical spectrum. Thereafter, the optical signal is passed through a system of optical elements (e.g. collimator lenses) to amplify the signal and to align the impinging light for optimum detection. At the photodetector (one PD or an array of PDs), the optical signal is converted back to electrical current.

The current signal is electronically pre-amplified by means of a transimpedance amplifier (TIA). A DSP with an analog-to-digital converter (ADC) is employed for transformation of the analog current signal into a digital signal and demodulation of the information bits.

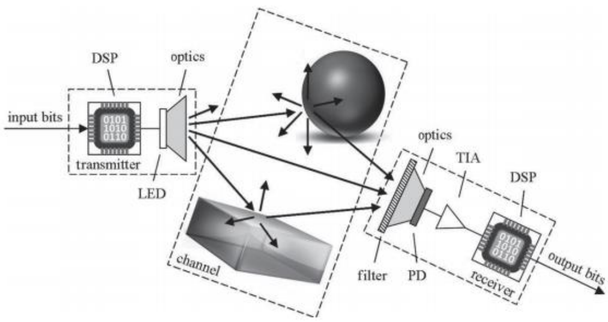

Figure 2.3: Transmission link in VLC (Hao Du, Guoning Xu, 2019).

2.5 Channel model of VLC

The first criterion is the degree of directionality of the transmitter and receiver. Directed links employ directional transmitters and receivers, which must be aimed in order to establish a link, while non-directed links employ wide-angle transmitters and receivers, alleviating the need for such pointing. Directed link design maximizes power efficiency, since it minimizes path loss and reception of ambient light noise.

On the other hand, non-directed links may be more convenient to use, particularly for mobile terminals since they do not require aiming of the transmitter or receiver. It is also possible to establish hybrid links, which combine transmitters and receivers having different degrees of directionality. The second classification criterion relates to whether the link relies upon the existence of an uninterrupted Line-Of-Sight (LOS) path between the transmitter and receiver. LOS links rely upon such a path, while Non-Line-Of-Sight (NLOS) links generally rely upon reflection of the light from the ceiling or some other diffusely reflecting surface. LOS link design maximizes power efficiency and minimizes multipath distortion. Non-LOS link design increases link robustness and ease of use, allowing the link to operate even when barriers, such as people or cubicle partitions, stand between the transmitter and receiver. The greatest robustness and ease of use are achieved by the non-directed-non-LOS link design, which is often referred to as a diffuse link.

This work (Hao Du, Guoning Xu, 2019) is focused on the TCP behavior analysis in an indoor environment, considering LOS links. The reason to not consider the NLOS is that the analyzed scenario is indoor scenario and there are no reflecting objects This means that the multipath components are almost negligible, except near to the walls, since the light intensity strongly depends on distance.

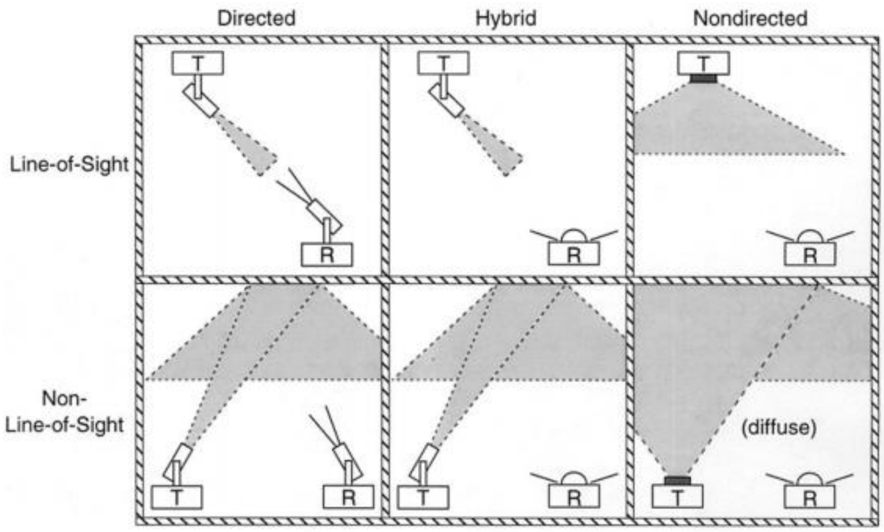

Figure 2.4: Classification of simple LOS & Non LOS light formed (Hao Du, Guoning Xu, 2019).

2.6 Equation of VLC Channel Model

The downlink Li-Fi channel model consists of three parts which are LoS path loss, multi-path effect in indoor scenarios and the frond-end filtering effect. Due to the limitation of the front-end devices, the Li-Fi system uses intensity modulation (IM)/direct detection (DD) and baseband bandwidth communication for downlink transmission. The LED and the Photodiode function as a low pass filter (J. J. D. McKendry et.al, 2015). In addition, due to the reflective indoor environment, receivers collect signals from multiple paths. Therefore, the channel impulse response (CIR) of downlink Li-Fi system can be expressed as (C. Chen, 2016):

$$h(t) = \left(\eta_{LoS}\,\delta(t) + h_{me}(t)\right) \otimes h_{fe}(t), \tag{2.1}$$

where ηLoS is the LoS channel gain; δ(t) is the Dirac delta function; hme(t) is the multi-path CIR and hfe(t) is the CIR caused by the front-end filtering effect. The corresponding frequency response of LiFi channels can be calculated by using Fourier transform:

$$H(f) = \int_0^{+\infty} (\eta_{LoS}\,\delta(t) + h_{me}(t)) \otimes h_{fe}(t)e^{-2\_ft}dt = (\eta_{LoS} + H_{me}(f))H_{fe}(f). \tag{2.2}$$

2.6.1 LoS Channel Gain

According to (Barry, 2015), the LoS channel gain can be written as:

$$\eta_{\text{LoS}} = \begin{cases} \frac{(\dot{m}+1)A_p}{2\pi(z^2+h_w^2)} g(\theta) T_s(\theta) \cos^{\dot{m}}(\phi) \cos(\theta), & \theta \leq \Theta_F \\ 0, & \theta > \Theta_F \end{cases}, \tag{2.3}$$

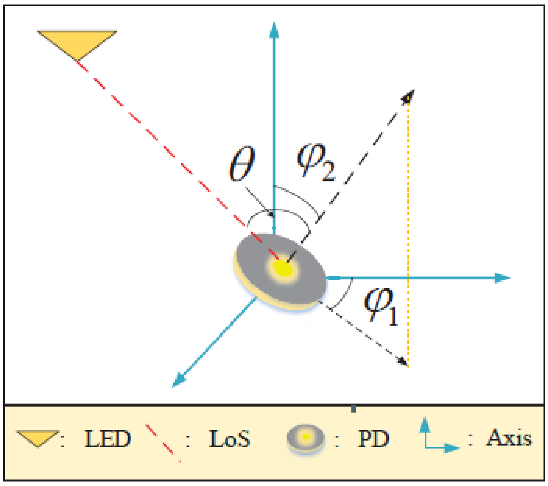

Figure 2.5: Illustrator of the angle of incidence to the Photodiode (Barry, 2015).

where m˙ is the Lambertian index which is a function of the half-intensity radiation angle θ1/2, expressed as m˙ = −1/ log2(cos(θ1/2)); Ap is the physical area of the receiver photo-diode; z is the horizontal distance from a Li-Fi AP to the optical receiver; hw is the height of the room; φ is the angle of irradiation; θ is the angle of incidence to the PDs; θF is the half angle of the receiver FoV; g(θ) is the concentrator gain; and Ts(θ) is the gain of the optical filter. The concentrator included at the receiver is to trade FoV for extra signal gain (Barry, 2015) and the concentrator gain can be written as:

$$g(\theta) = \begin{cases} \frac{\chi^2}{\sin^2 \Theta_F}, & 0 \leq \theta \leq \Theta_F \\ 0, & \theta > \Theta_F \end{cases}, \tag{2.4}$$

where χ is the refractive index. The optical filter that is made of glass or plastic is used to remove unwanted signals for PDs. In general, the gain of optical filters is assumed to be 1 with $\theta \leq \theta_F$.

The PD at each Li-Fi receiver may have horizontal and vertical tilts, which affect the angle of incidence to the PDs. As shown in Figure 2.5, in Cartesian coordinates, the direction vector of the PD can be expressed as:

$$d_1 = (\cos(\phi_1)\sin(\phi_2), \sin(\phi_1)\sin(\phi_2), \cos(\phi_2)), \quad (2.5)$$

where ϕ1 is the horizontal orientation angle which follows a uniform distribution between 0◦ and 360◦; and ϕ2 is the vertical orientation angle which follows a uniform distribution between 0o and θPD, where 0◦ ≤ θPD ≤ 90◦ is the maximum vertical orientation angle. A PD of θPD = 0o is perpendicular to the floor. In this case, the angle of incidence to PDs is equal to the angle of irradiation. The distance vector from a user to a Li-Fi AP is denoted by:

$$d2 = (x_a - x_u, y_a - y_u, z_a - z_u), \quad (2.6)$$

where (xa, ya, za) and (xu, yu, zu) are the coordinates of the LiFi AP and the user, respectively. The angle of incidence to the PDs can be expressed as:

$$\theta = \arccos < d1, d2 >, \quad (2.7)$$

where <,> is the inner product operator.

2.6.2 Multipath Component

Referring to (F. Miramirkhani and M. Uysal, 2015) the characteristics of non-LoS (NLoS) channels in the indoor environment in Li-Fi systems have been widely studied. It has been showed that the NLoS channels are mainly due to diffused reflections caused by human bodies, furniture and other objects, and are difficult to predict and model. In (F. J. Lopez-Hermandez and M. J. Betancor, 1997), ray-tracing technique based approaches are developed to calculate the NLoS channel impulse response caused by internal surface reflections. In (V. Jungnickel, V. Pohl, S. Nonnig, and C. von Helmolt, 2002), according to simulations and measurements, an approximated diffused channel model in the frequency domain for Li-Fi systems is proposed:

$$H_{\mathrm{me}}(f) = \frac{\rho A_p e^{-j2\pi f \Delta T}}{A_r(1-\rho)(1+j\frac{f}{f_c})}; \quad (2.8)$$

where Ar is the area of the indoor scenario surface; ρ is the reflectivity of the walls; ΔT is the delay between the LoS signal and the onset of the diffuse signals; and fc = 1/2πτ is the cut-off frequency of the diffuse optical channel with τ denoting the transmission delay of a photon via reflective channels.

2.6.3 Front-end Filtering Effects

The frequency response of a LED shows a low-path characteristic because of the long carrier lifetime in the device active region and the large capacitance of the LED device (T. Komine, S. Haruyama, and M. Nakagawa, 2006). In order to characterize the LED low pass filtering effect, several expressions are used as approximations. In (C. Chen, D. Basnayaka, and H. Haas, 2016), it has been shown that the normalized magnitude response in decibel can be approximated to be inversely proportional to the frequency, which can be expressed as:

$$H_F(f) = \exp(-\frac{f}{v_e f_0}), \quad (2.9)$$

where f0 is the 3 dB cut-off frequency of the front-end filtering effect and ve = 2.88 is the fitting coefficient, enabling to achieve |HF (f0)|2 = −3 dB.

2.7 Modulation schemes of VLC

One of the main differences between VLC and RF is that, in VLC, data cannot be encoded in phase or amplitude of the light signal because they use incoherent solid-state lighting LEDs as front-end devices due to their low cost (T. Komine, S. Haruyama, and M. Nakagawa, 2006).This means that the information must be encoded in the varying intensity of the emitting light wave and the demodulation depends on direct detection at the receiver. Another difference from the other types of communication is that any modulation scheme for VLC should not only achieve higher data rate but should also meet the requirements of perceived light to humans.

These requirements about perceived light can be characterized by following two properties:

- Dimming: The nowadays LED can be dimmed to an arbitrary level and a user may choose an arbitrary level of dimming depending on the application (different levels of luminance are required depending on the activity performed in the place illuminated (S. Dimitrov and H. Haa, 2015) or desired energy savings, but the communication should not be affected by the dimming. Furthermore, considering the fact that the relation between the measured light and the perceived light is non-linear (DiLaura, 2011) a lamp that is dimmed 1% of its measured light is perceived to be 10% dimmed by the human eye, as shown in Figure 2.5, the data should be modulated in such a way that any desired level of dimming is supported**.**

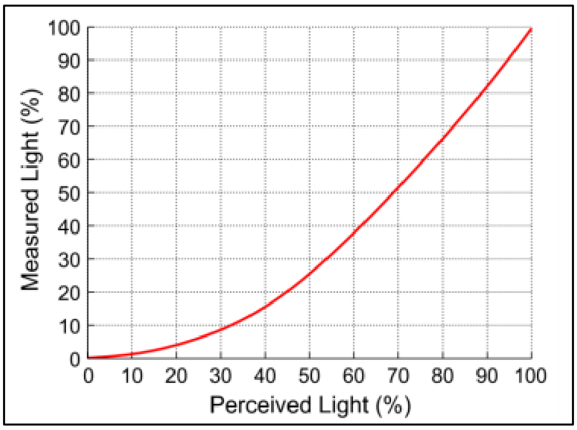

Figure 2.6: Measured light vs human's eye perceived light (DiLaura, 2011).

- Flicker mitigation: the flickering, that is the changing of the light intensity, can cause serious detrimental physiological changes in humans (S. M. Berman, D. S. Greenhouse, I. L. Bailey, R. D. Clear, and T. W. Raasch, Pubs). Therefore, to avoid that the fluctuations in the brightness of light are perceivable by humans, it is necessary that changes in the light intensity should happen at a rate faster than human eye can perceive. IEEE 802.15.7 standard (Xiaojie Zhao, Dandan Hou, Yandan Lin, Wei Xu, 2018) suggests that flickering (or change in light intensity) should faster than 200 Hz to avoid any harmful effects. This means that any modulation scheme for VLC should mitigate flickering while providing higher data rate.

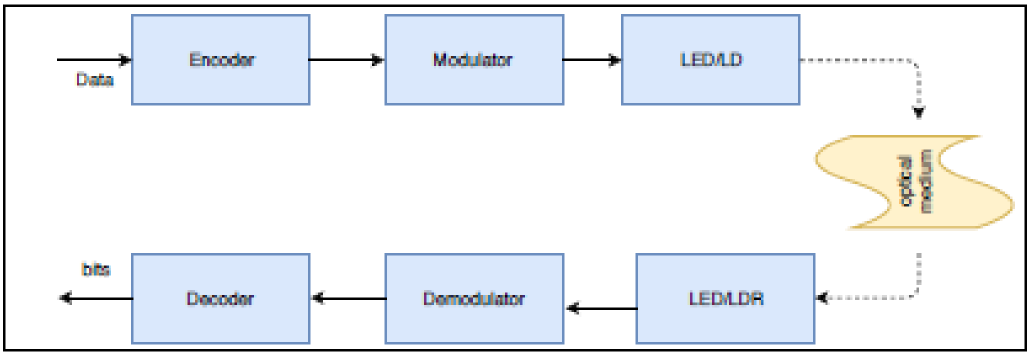

Figure 2.7 Physical layer implementation of Li-Fi system (Anurag Sarkar, Shalabh Agarwal, and Asoke Nath, 2015)

The layer defines the physical configurations of the devices. It specifies the relationship between the device and the physical medium. The physical layer establishes the communication between the transmitter and the receiver. The block diagram of the general physical layer implementation of the Li-Fi system is shown in Figure 2.6. The encoded data to proceed for modulation such as OOK or OFDM. The data is ready to transmit to the transmitter by LED / LD (Laser Diode) for transmission. The data is transmitted as a variation of light intensities. At the receiver end, photo detector or LED is used to receive the data. The receiver synchronizes with the transmitter to establish communication. Next, the data is processed with demodulation and decode with the same technique used at the transmitter.

Li-Fi systems use the following modulation schemes such as OOK, Variable Pulse Position Modulation (VPPM), Colour Shift Keying (CSK), Sub-

Carrier Inverse PPM (SCIPPM), SIM-OFDM (Sub-Carrier Index Modulation OFDM) (Anurag Sarkar, Shalabh Agarwal, and Asoke Nath, 2015). In OOK, the LED is not switched off completely in the off state, but the reduction in the level of intensity is performed. OOK modulation does not require prior knowledge of transmitter or receiver characteristics. The main advantage of using OOK is its easy implementation and highly responsive with a white LED (Sarah Bahanshal, Hibatallah Alwazani, M. A. Majid, 2019).

The literature reports several modulation techniques that have been investigated. In following, the advantages and downsides inherent to each method have been summarized in Table 1.0 below.

Table 1.1 Various modulation techniques used by researcher.

Modulation	Details
On-Off Keying (OOK)	LED ON and OFF states are used to encode 1 and 0 respectively. Because OOK symbols need to be short enough to avoid a visible change in the LED brightness, which is the flickering effect, this scheme is affected by the ambient noise. OOK can also produce human perceivable LED flickering in the case of long sequences of 0 or 1 in the transmission data. That's why OOK is often combined with a duty-cycle (DC) balanced run-length limited (RLL) code like Manchester (Ferrandiz-Lahuerta, J., Camps-Mur, D., and Paradells-Aspas, 2015), (Hao, J., Yang, Y., and Luo, J, 2016).
Frequency Shift Keying (FSK)	To address the limitations of OOK, (Lee, 2015) have proposed to use FSK where different symbols consist of many ON-OFF bands at different frequencies. FSK reduces the demodulation error due to longer symbol duration and multiple ON-OFF bands in each symbol. That leads to a capacity an order of magnitude lower than OOK, with a throughput of 90.56 bps and 10 bps in (Lee, 2015).

Colour Shift Keying (CSK)	This can be used if the illumination system uses RGB type LEDs. By combining the different colours of light, the output data can be carried by the colour itself and so the intensity of the output can be constant The disadvantage of this system is the complexity of both the transmitter and receiver.
Orthogonal Frequency Division Multiplex (OFDM)	This modulation scheme has been widely used for digital TV and radio and also for Wi-Fi. It can be modified for use in optical communications. OFDM uses a set of sub-carriers each at different but harmonically related frequencies. There are a number of advantages including good spectral efficiency, but this method is quite complex to implement.

2.8 Concept of Li-Fi research

In 2011, Harald Haas demonstrated Li-Fi communication at TED Global. Li-Fi was listed as one of the top 50 innovative technologies in TIME Magazine 2011. Li-Fi is a high speed bi-directional fully connected, visible-light wireless communication system and is complementary to Wi-Fi, which uses radio frequency for communication. Li-Fi also lends support to the IoT. Li-Fi is an innovative technology that is composed to impact many industries. Li-Fi is a fundamental 5G technology. This technology can unlock the IoT, pilot Industry 4.0 applications, light-as-a-service (LaaS) in the lighting industry (Haraald, 2018)

A speed up to 10 Gbps is obtained using Li-Fi, which is 250 times more than the speed of super-fast broadband (Khan, 2017)The RF spectrum is only a fraction of the entire electromagnetic spectrum. The visible light spectrum and the Infrared (IR) spectrum are unregulated and offer 780 THz of bandwidth. The visible light spectrum extends from 380 to 780 nm in wavelength. (Haraald, 2018)

Li-Fi has entered in IEEE standardization and can be adopted for several specific industrial use cases beyond its current smart lighting scope. IEEE 802.15.7 standard defines a Physical and MAC layer for short-range optical wireless communications using visible light as the communication medium. According to (Mehmet Fatih Isik, 2017), in the industrial manufacturing process, the process must be completed with high speed and security apart from the product quality. Hence, deploying new communication strategies in the industries are evolving day by day.

In comparison, Li-Fi technologies preferred over Wi-Fi because of the high-speed data transmission rate and security in wireless communication systems (Mehmet Fatih Isik, 2017). When Wi-Fi systems are replaced with Li-Fi, the receivers must be positioned in specific locations, where light from transmitter is uninterrupted. Thus, the line-of-sight problem is solved. Besides, the production process is faster by using Li-Fi. Therefore, internet connection can be provided without any interruption to the robotic arms or any other devices.

(Koh, 2018), proposed a scheme for device management and data transport in IoT networks using Visible Light Communication (VLC). In this concept, uni-directional transmission from the VLC transmitter is used to send the location-based VLC data. From the VLC receiver, the data is forwarded to aggregation agents and a central server in the network.

(Vinayagam Mariappan, 2017), proposed a concept of “Internet of Light” (IoL). Integrating IoT agent on IoL gateway and proposed different communications integrated with VLC such as VLC - PLC, RF - VLC and Ethernet - VLC link to create heterogeneity gateway for IoT devices.

Recently, according to (Weizhi Zhang, 2015), research on VLC indoor positioning systems with simple system configurations. An indoor positioning system based on VLC was introduced, with no synchronization requirement on the transmitters.

(Aarthy, 2017), proposed Li-Fi communication for transmitting audio, text, navigation using text to speech. One-way communication and bi-directional communication are tested with Arduino and IR, LEDs, and photodiodes.

(Mostafa Zaman Chowdhury, 2018), explains about industrial communications such as device-to-device (D2D), machine- to-machine (M2M), chip-to-chip, device/machine-to-user, user-to-device/machine. These communications can be achieved using VLC technologies.

(T. M. Darshith et al., 2017), proposed LED as a photo detector to receive optical messages using the same LED that is used for transmission a setup, which reduces the complexity of the device. The capacitance of LED discharges at different speeds depending on the intensity of incoming light. The discharge speed is directly proportional to the intensity of light. The maximum achievable data rates in Li-Fi are in the ascending order of phosphorous coated LED, red, green and blue (RGB) LEDs, Gallium Nitride (GaN) micro LEDs and laser-based lighting (Sarah Bahanshal, Hibatallah Alwazani, M. A. Majid, 2019).

(Mohit Sanjeevkumar Gujar, Shrikant Velankar, Arun Chavan, 2016) implemented two prototype, stereo and audio streaming methods utilizing VLC. Pulse code Modulation Streaming (PCM) proto-type and MP3 streaming prototype. It was observed that system complexity is low in PCM prototype when compared with that of MP3. For higher data rates the audio quality reached to an optimum level and when the channel length is increased the audio quality drops to a minimum level. In paper (K. Bhavya, 2018), the researcher discussed about Power-line Communications (PLC), where power lines are used to medium of communications. Integrated system with PLC and VLC is a smart way for broadband access for home networking giving low cost and efficient lightning. For receiving higher data rates in MHz, the PLC channel was simulated using DMT-QAM modulation scheme.

About combining Li-Fi technology and Energy Wireless Sensor technologies for solving the energy feeding issues of energy harvesting sensors is discussed in (Mohit Vasuja, 2018). The sensors could feed themselves by harvesting energy from the LED light and also communicated each other using Li-Fi. This combination technology could bring great benefits and enable good features in the design of high performance buildings.

(T. M. Darshith, Chandana Bhatt, 2017) reviews about Li-Fi technology's applications, future expansion and working of the technology. It also states the advantages of using this technology over the other data transfer methods like Wi-Fi, Infra-red, and Bluetooth. A Low complexity and low cost VLC application system which give high speed transfer rate is proposed. A Li-Fi or VLAN system with a bi-directional transfer of 100 Mb/s based on OOK modulation without a blue filter is obtained with a transmission distance of 1.9m.

In short, the existing concepts and current work regarding industry 4.0, smart home with IOT capabilities and Li-Fi communications are discussed. After considering all the concepts as a background and ground truth, this thesis proposes the Li-Fi communication protocol for distributed structures in future smart home.

Table 1.2 Summary of comparisons between related journals.

Name/Year	Title of Project	Objectives/Purpose	Method Use	Result
(P. Prakash, Rinki Sharma, S Sindhu, Tejaswini Shankar, 2017)	Visible Light Communication using Solar Panel	Improve efficiency of area line of sight received from the LED.	Matlab GUI LED Solar Panel	Provide alternative receiver usage of Li-Fi systems.
(Mohit Sanjeevkumar Gujar, Shrikant Velankar, Arun Chavan, 2016)	Realtime audio streaming using Visible Light Communication	Measure transmit of audio waves as input via light source medium.	LED Photodetector Speaker	Transmission audio of 3 meter is possible by using Visible Light Communication.
(K. Bhavya, 2018)	Simplified Integration of Power Line and Visible Light Communication	Electric power cable sharing for communication technology with PLC and VLC	Simulink Matlab	Creating cost effective hardware instead of power outlet uses for charging but creates a medium of light source communication path.

(Mohit Vasuja, 2018)	Image Transmission Using Li-Fi	Test the capability of Li-Fi system image transfer by using few conventional modulation techniques.	Proteus MPLAB IDE IR LED Photodiode PIC Controller	Edited image were transferred by Li-Fi system is in numeric array processed in Microcontroller tool were success.
(T. M. Darshith, Chandana Bhatt, 2017)	Prototyping of a Li-Fi communication system	Testing intensity of LED and lasers to transmit message via various distance.	HyperTerminal LED LASER PhotoDiode	LASERS provide better range compared to LED in Li-Fi transmission
(Sarah Bahanshal, Hibatallah Alwazani, M. A. Majid, 2019)	Design of RGB Laser Diode Drivers for Smart Lighting and Li-Fi using MATLAB GUI	Using RGB Lasers as light source medium to transmit message.	Proteus RGB LASER Laser Driver ARDUINO UNO MATLAB GUI	Laser Driven RGB LASER is needed to convert RGB to a single white light source

(Shruti Srivastava, 2018)	Highway Navigation System using Light Fidelity Technology	Positioning system in urban environment for highway routing to replace radio based wireless technologies.	Proteus Atmega328 LED LDR Module	Beneficial in managing traffic and setting up smart city-based communications to urban environment.
(S. Sudha, D Indumathy, A Lavanya, M Nishanthi, D Merline Sheeba, V Anand, 2016)	Patient monitoring in the hospital management using Li-Fi	Monitoring various sensors added on patients to create a greener communication system in hospitals.	MATLAB GUI Various Health Sensors Photo diode LED Driver PIC 16F877A	Solve issues such as shortage of radio frequency bandwidth and also allow internet where traditional radio-based wireless is not allowed such as aircraft or hospitals.
(O. I. Romanov, Y. S. Hordashnyk, T. T. Dong, 2017)	Method for calculating the energy loss of a light signal in a telecommunicati on Li-Fi system.	Determine the rational use of Li-Fi system and mathematical apparatus on efficiency output delivered	Mathematical model of light signals in an office.	Proposed effects of the emission angle of light signal, angle of incidence and distance between receiver & transmitter.

2.9 Summary

This technology has a bright scope in future. This technology demonstrated a solution to the problem of integrating Visible Light Communication technology with present infrastructure without having to make major changes to that infrastructure Visible Light Communication is a rapidly growing segment of the field of communication. There are many advantages and challenges to using VLC. VLC will be able to solve many of the problems people have been facing for many years, mainly environmental and power usage issues.

Overall, there are several themes in the prior work on simulating the IoT integration with Visible Light Communication. First, there is a consensus that there is a benefit to simulation. This can range from optimizing devices or apps, to testing brand new ideas of how to coordinate IoT devices. There is also a general trend toward looking ahead rather than backwards. This means creating accurate simulations of how devices behave and allows the technologies to be tested with new frameworks to see what's involved in coordinating, while also providing an educational benefit in observing how different devices communicate in the first place.

VLC is still in its beginning stages, but improvements are being made rapidly, and soon this technology will be able to be used in daily lives. However, people have to belief that the VLC system will become one of the most promising technologies for the future generation in optical wireless communication.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the software and hardware implementation of the Li-Fi transceiver and design of the initial build modules. The experiments are conducted to identify a suitable Li-Fi transceiver pair, in the context of reliability and maximum communication distance. The integration of Li-Fi communication on the modules was performed with two different prototypes. This section also discusses the overview design choices, requirements, software architecture and implementation of the Li-Fi protocol such as:

- Design and construct circuit of Visible Light Communication by display any data on LCD, implementing variable light transmitter source and variable function of independent light source.
- Program the code that will be powered by the controller and integration of IOT based elements.
- Assembly the circuit based on working prototype tested and troubleshoot if there is any problem occurred.

Researcher will begin with the explanation on detail about the block diagram of the project and the flow chart of project in this part of methodology. After that, the information of the component that used to complete this project. This project consists electrical and electronic component parts that will represented on the next section. Lastly, researcher will explain about the expected result on the working prototype and the project flow in Gantt Chart.

3.2 Block Diagram

This project was reviewed to overcome some issues that were faced during the previous works, like communication range between the transmitter and receiver was low, due to prolonged use the chances for the system to get destroyed was high, the inference and noise of the signal was high, and reduce installation cost.

3.2.1 Transmitter

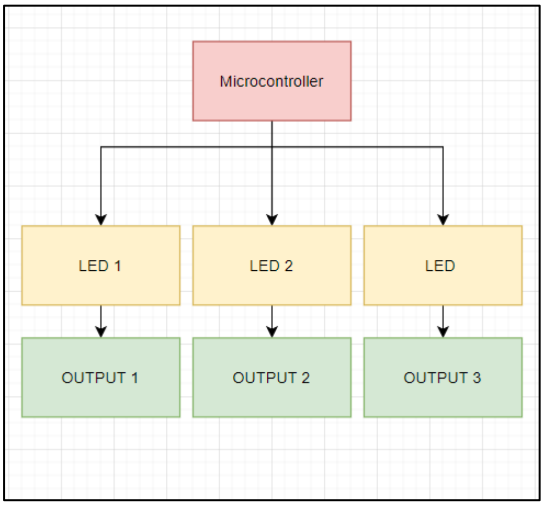

Figure 3.1:General Block Diagram of transmitter Li-Fi system.

Depending upon the information to be transferred, data from the PC such as text message or programmed code is all transferred to the Arduino via direct connection from Universal Serial Bus (USB). A testing dashboard of input text message via MATLAB will be created to testing out the text output by using simulation method. The block diagram displays the data is transfer by using Single Input Single Output (SISO) which one LED will input single data with single output outcome.

3.2.2 Receiver

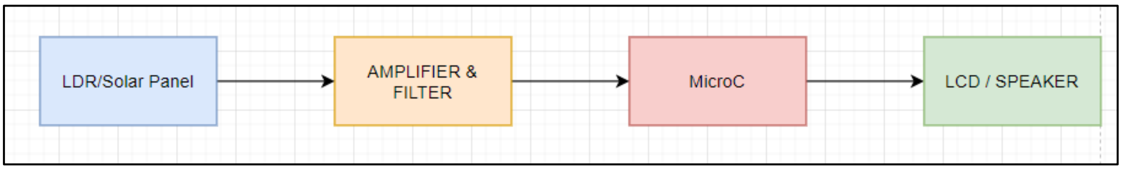

Figure 3.2: General Block Diagram of transmitter Li-Fi system.

The information transmitted from the Li-Fi transmitter is received by the Li-Fi receiver based on Figure 3.2 and is amplified and sent to the Arduino. Then depending upon the information, the processed data is sent to the corresponding output. Then, LCD Display will display the text data or speaker that will produce sound to indicate the working output of this project.

3.3 Flowchart

The design implemented in this project is described below,

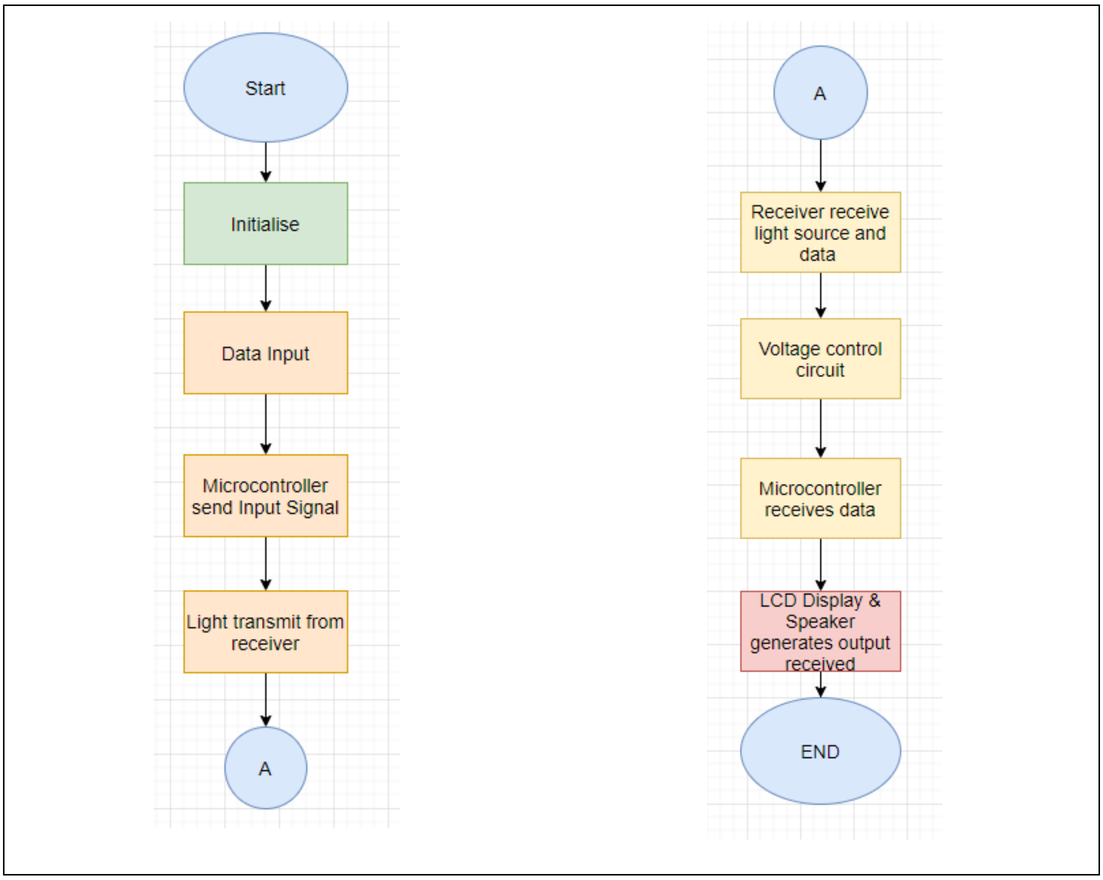

Figure 3.3: General Flowchart of Visible Light Communication.

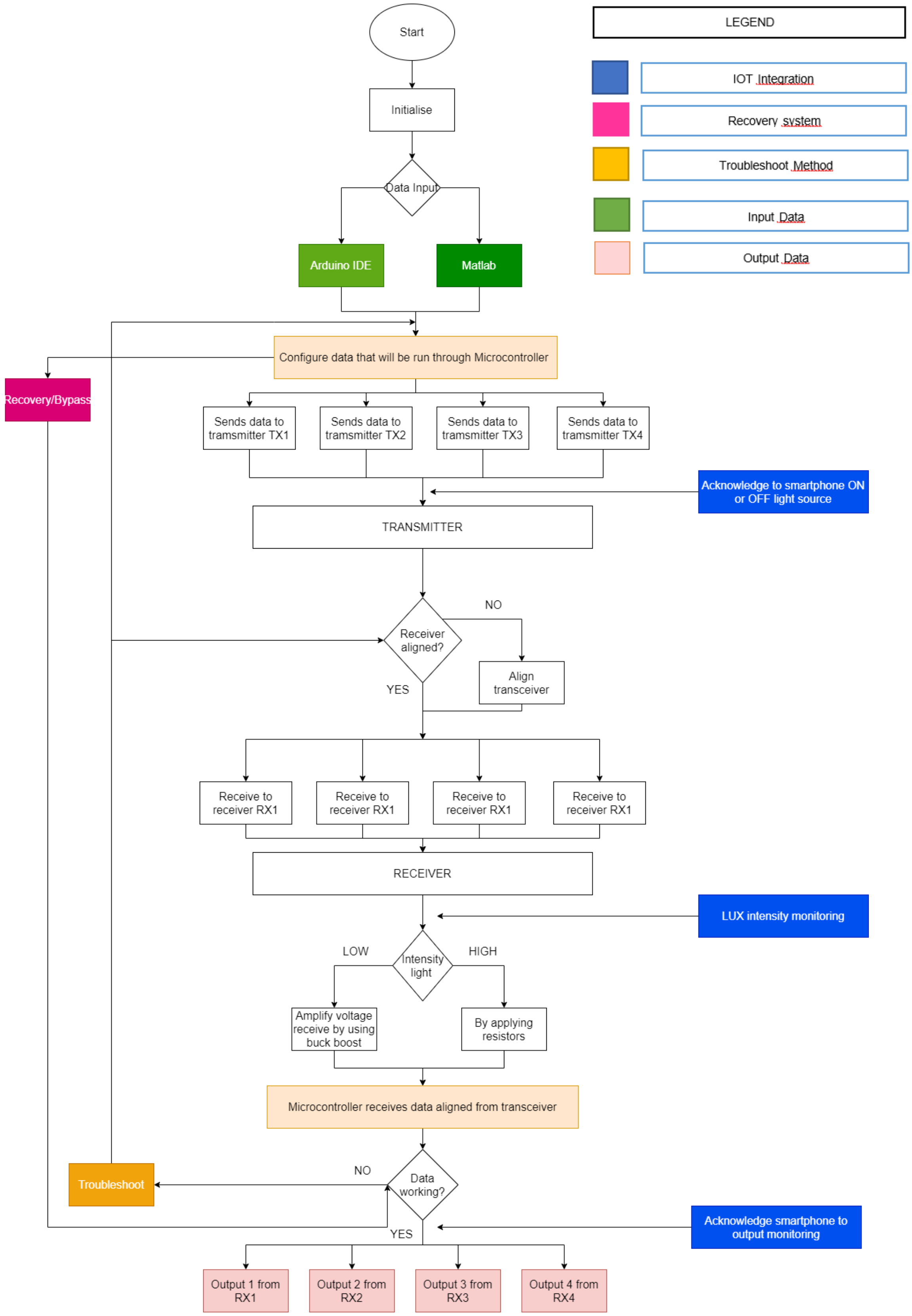

Figure 3.4: Detailed flowchart of Visible Light Communication.

3.4 Hardware Design of Li-Fi Transceiver

The hardware design of Li-Fi transceiver can be designed in two different variations. The Arduino-Mega 2560 is used as the controller, and blue color LED is used as transmitter and receiver. A 270 Ω resistor is used at the transmitter side, and 2 MΩ resistors are used at the receiver end. The LED based Li-Fi transceiver, shown in Figure 3.5. The LDR based Li-Fi transceiver is shown in Figure 3.6. LED as transmitter and LDR as the receiver. 270 Ω resistors are used at the transmitter and receiver end. The transmitter is connected to GPIO digital pin D4 and receiver is connected to GPIO analog pin A0 of Arduino-Mega 2560 controller.

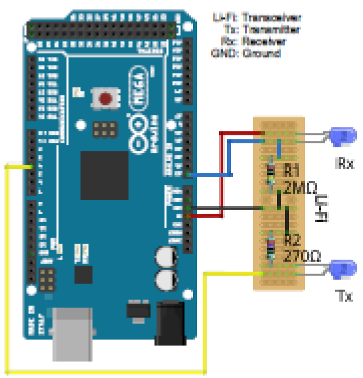

Figure 3.5: LER based Li-Fi transceiver.

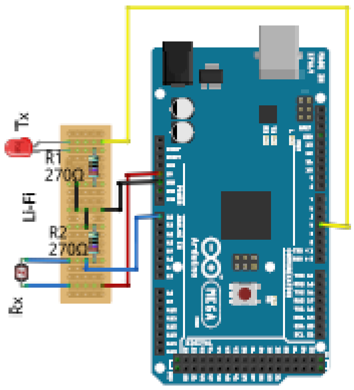

Figure 3.6: LDR based Li-Fi transceiver.

In the smart home-based model, a four-way Li-Fi transceiver is attached to the model as shown in Figure 3.7. The four-way Li-Fi transceiver is achieved using multi transceivers based on Manchester transmission algorithm. The Arduino controller is capable of handling the four transceiver interfaces. The receivers are connected to the analog GPIO pins from A0 to A3. The transmitters are connected to the digital GPIO pins from D4 to D7.

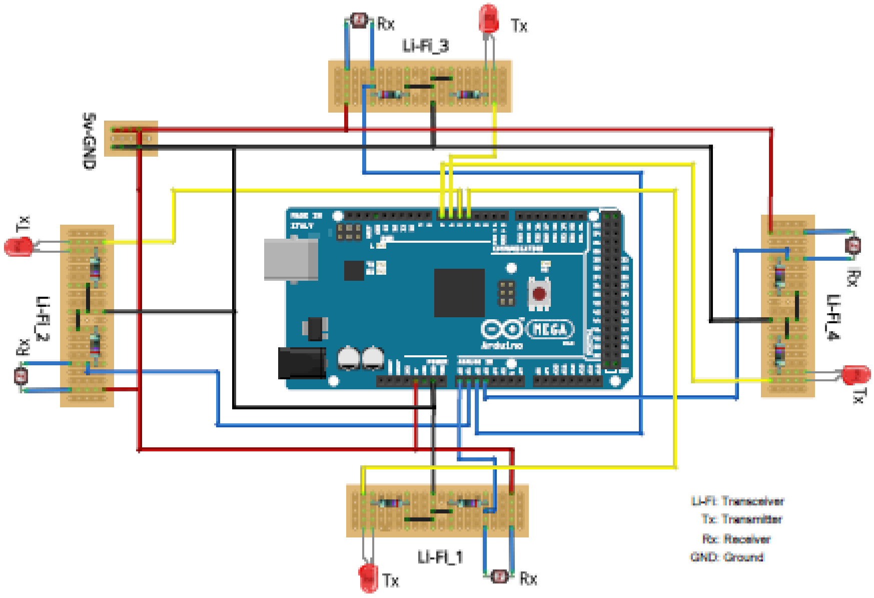

Figure 3.7: Four Way Li-Fi Transceiver.

3.5 Project selection setup

In this smart home prototype project, there are several components and software will be used to complete this project such as Arduino Mega 2560, Raspberry Pi 3A+, relay, LCD, LED LDR, Solar Panel, smartphone, and other parts selection listed on Table 1.6. All components and software will be explained according to the section below.

3.5.1 Arduino Mega 2560

Arduino is open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It is intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments. Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone, or they can communicate with software running on a computer.

An Arduino-Mega 2560 is used as a development board because it is inexpensive, powerful tool to interface with the sensors and supports different development platforms. The Arduino-Mega 2560 has 16 MHz crystal oscillator which is used for the controller clock. The Arduino has both analog and digital General-Purpose Input and Output (GPIO) pins and an inbuilt Analog to Digital Converter (ADC). Universal Serial Bus (USB) interface is used to program the Arduino board.

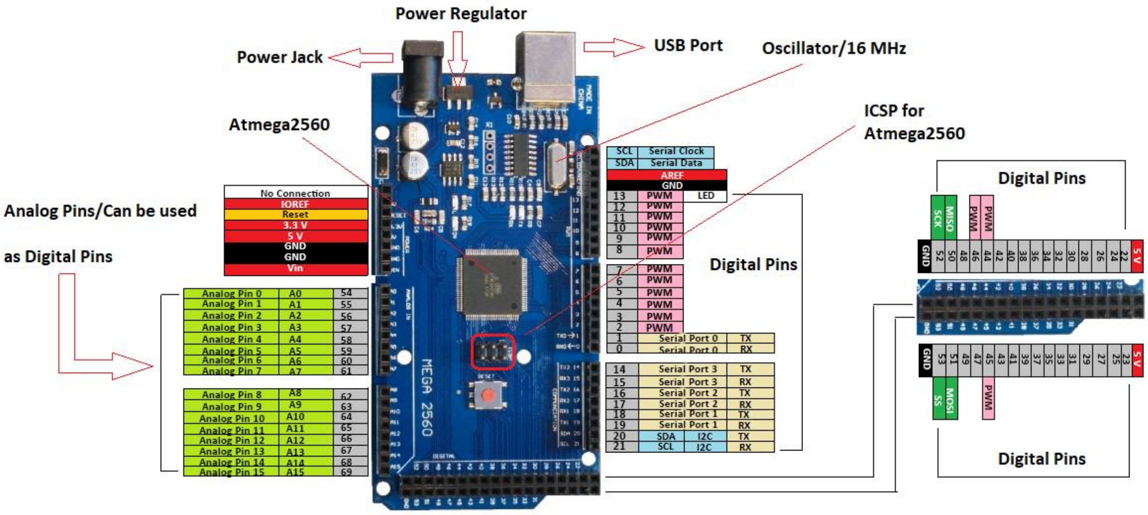

Figure 3.8: Arduino Mega 2560 board pinout.

3.5.2 Raspberry Pi 3 Model A+

The processor for the Pi 3 A+ has been benchmarked ten times faster than one used in the original A+. But the A+'s biggest advantage over its predecessor is connectivity. Although the original A+ did not have wired or wireless networking, the Pi 3 A+ provides the same powerful 802.11ac Wi-Fi and Bluetooth 4.2 found in the B+, making data on and off the board much easier to access. That being said, the A+ was never really intended to be used as an everyday device, with its smaller size and lower power consumption making it more of a board for home-made, probably battery-powered, electronic hardware to create. The price is reasonable for our project. The A+ model seemed to transfer the file more rapidly than the B+.

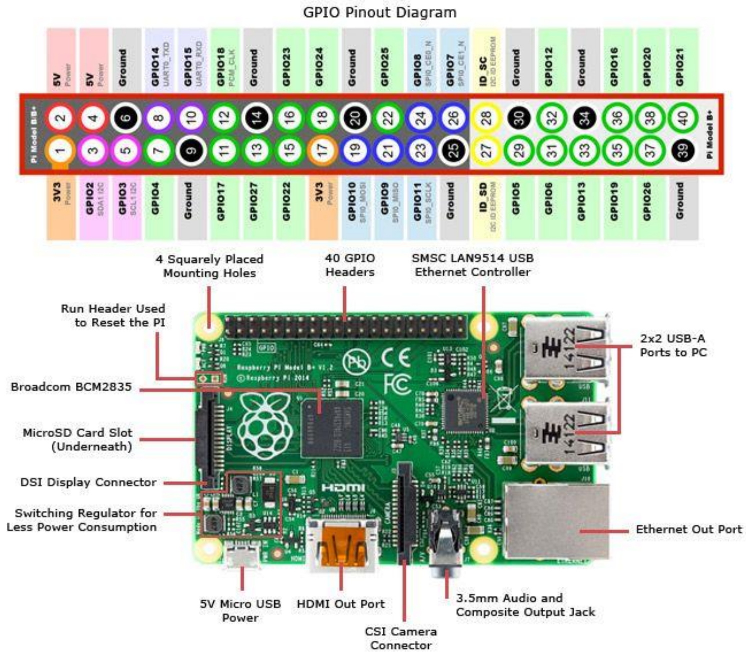

Figure 3.9: Raspberry Pi 3 Model A+ board pinout.

Table 1.3: Specification of Raspberry Pi 3 A+ model.

Processor	Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4 GHz
Memory	512MB LPDDR2 SDRAM
Connectivity	2.4 GHz and 5 GHz IEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2/BLE
Access	Extended 40-pin GPIO header
Video & sound	• 1 × full size HDMI • MIPI DSI display port • MIPI CSI camera port • 4 pole stereo output and composite video port
SD card support	Micro SD format for loading operating system and data storage
Input power	• 5 V/2.5 A DC via micro USB connector • 5 V DC via GPIO header

3.5.3 16GB Micro SD Card With NOOBS For Raspberry Pi

The Official Raspberry Pi New Out of Box Program (NOOBS) preloads this 16 GB MicroSD Card. This is the best way to get started with Raspberry Pi Boards for both beginners and first-time users (this will work on all RPi models). The researcher may need to use a variety of common operating systems listed in Table 1.4 for various projects.

Figure 3.10: 16GB MicroSD Card with NOOBS.

Table 1.4: Raspbian Type OS

Rasbian Type				
Raspbian Full	Raspbian Lite	LibreElec	Lakka RPI4	TLKOX
A full operating system with a graphical interface for applications and games	Commonly used for command-line access instead of a graphical interface	A very popular Media Center	For Retro Gaming	Trial version, Debian-based thing client

3.5.4 Light Diode Resistor (LDR)

LDR is Light Dependent Resistor. LDRs are made of materials made from semiconductors to allow them to have their light-sensitive properties. There are several types of material, but one is common and cadmium sulphide (CdS) is used. Those LDRs or Photo Resistors operate on "Photo Conductivity" which that if light falls on the LDR surface (in this case) the element's conductance decreases, or in other words, the LDR 's resistance falls when the light falls on the LDR surface. This property of decreasing resistance for the LDR is achieved because it is a function of the material used on the surface of semiconductors.

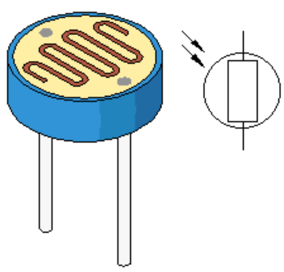

Figure 3.11: Sample component of LDR.

3.5.5 Relay

Relay is an electrical operating switch. Mostly relays use an electromagnet to operate a switch. In other word, Relay are switches that used to open and close circuit electromechanically or electronically. When the relay in normally open (NO), it means the relay contact is an open contact when the relay is not operating. While the relay contact in normally closed (NC), the relay contact is a closed contact when the relay is not operating. The relay will change their state when the electrical current is applying.

Figure 3.12: Sample of relay.

3.5.6 Solar Panel

A solar panel could be used to act as output in a larger scale. However, the interference of noise such as sunlight could distract the data obtain by the transmitter. Thus, the solar panel also could be beneficial when testing in a larger scale of Visible light communications or initial build for prototype testing rather than only using the LDR.

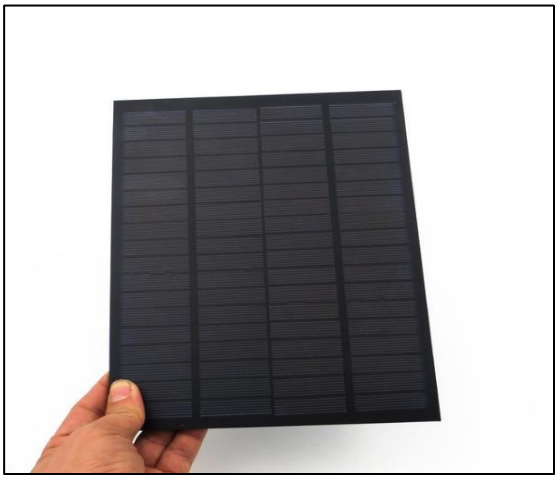

Figure 3.13: Solar Panel HX-5W/18V

Table 1.5: Solar panel specification.

Model No.	HX-5W/18V
Cell type	Monocrystalline
Peak power (Pmax)	10Wp
Power tolerance range (%)	$\pm$13%
Open circuit voltage / Voc(V)	22.3
Max.power voltage / Vmp/V)	17.8
Short circuit current / Isc(A)	0.61
Max.power current / Imp(A)	0.56
Maximum System Voltage(V)	600V
DC Dimension(mm)	185x415x18

3.5.7 Light Emmiting Diode (LED)

In the simplest terms, a light-emitting diode (LED) is a semiconductor device that emits light when an electric current is passed through it. Light is produced when the particles that carry the current (known as electrons and holes) combine together within the semiconductor material.

Since light is generated within the solid semiconductor material, LEDs are described as solid-state devices. The term solid-state lighting, which also encompasses organic LEDs (OLEDs), distinguishes this lighting technology from other sources that use heated filaments (incandescent and tungsten halogen lamps) or gas discharge (fluorescent lamps).

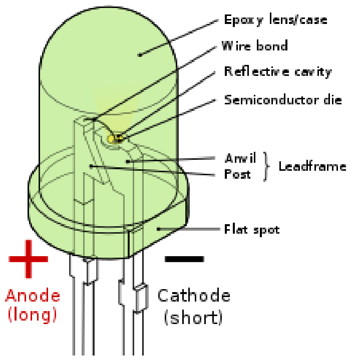

Figure 3.14: LED Layout.

3.5.8 Liquid Crystal Display (LCD) 16X2

Frequently, a program must interact with the outside world using input and output devices that communicate directly with a human being. One of the most common devices attached to a controller is an LCD display. Some of the most common LCDs connected to the Arduino are 16x2 and 20x2 displays. This means 16 characters per line by 2 lines and 20 characters per line by 2 lines, respectively. In this project, this LCD will act as output to the visible light communication system by showing text data.

3.5.9 Power Transistor

If a transistor designed to these concepts can handle more than 1 A of collector current, it is generally considered to be a power transistor. Such transistors must have low output resistance to deliver large load currents, and good junction insulation to resist high voltages.

Transistor must also dissipate heat very quickly to avoid overheating. The collector/base junction must be as large as possible, as most heat is generated in the heat sink. For this project, the researcher are using TIP122 so that large LED's can also be driven by our system.

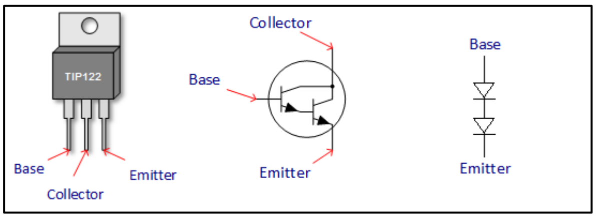

Figure 3.15: TIP 122 Power Transistors pinout.

The components required to build Li-Fi transceivers and other resources are given below:

Table 1.6: Selection Parts involved in smart home prototype.

Item	Parts involved
Controller	Arduino Mega 2560 / Raspberry PI 3A+
Transmitter	LED / Bulb / Laser driver
Receiver	LDR / Solar Panel
Buck Boost/ Amplify	TIP 122 Power Transistor
Power Source	9V Battery / Direct Plug in source
Misc.	Relay, Resistors
Output	LCD Display, Speaker
IOT Features	Condition LED, Intensity LUX, Output Monitoring
Software	RIOT-OS, Proteus, TinkerCAD, MATLAB

3.6 Software setup

RIOT-OS is used as a development platform. RIOT-OS provides a variety of functions to implement the Li-Fi protocol. The operating system provides the multi-threading functionality for designing the multiple transceivers for each node. The outputs are connected to the Arduino and control logics are programmed on RIOT-OS base. The design of a Li-Fi transceiver is explained on the earlier block diagram works.

The circuit schematics are designed by using Proteus software tool. Proteus is an electrical device simulation and design tool developed by Labcenter Electronics and Circuit architecture electronics. It also has functionality of 2D CAD drawing. It is a software package that includes both schematics, simulation, and PCB design. ISIS is the program for drawing schematics and simulating circuits in real time. The simulation enables human control during runtime, thereby offering simulation in real time. ARES is used for PCB modelling. It has a 3D view of the designed PCB as well as components displaying output. The designer can create 2D drawings for the product as well. ISIS has a large collection of components in its library. It has sources, signal generators, measuring and analytical devices such as oscilloscope, voltmeter, ammeter etc., probes for real-time monitoring of circuit parameters, switches, monitors, loads such as motors and lamps, discrete components such as resistors , capacitors, inductors, transformers, optical and analog Integrated circuits, semi-conductor switches, relays, microcontrollers, processors.

The component holders are shown in Figure 3.5, 3.6 and 3.7 are designed using an online 3D modelling design tool known as Tinkercad. Tinkercad is a free set of software resources online that allows people around the world to think, build and construct. Tinkercad, a user-friendly design platform enabling even the most basic beginners to build a 3D-printable model. The website allows users to upload own model to share designs seamlessly.

3.7 Expected Result

Li-Fi technology has several advantages over Wi-Fi. In Li-Fi LED’s are used for both illumination and data transmission purpose whereas in Wi-Fi Electromagnetic waves are used for data transmission. Nowadays, this is an emerging technology which is used in several applications such as security, navigation in urban environments and cellular communication.

In this technique the data is being fed to LED driver circuit. The microcontroller is present in transmitter which has the data of simple smart home usual activity programmed in it. The proposed design contains LED as transmitter for transmitting the information. At the receiver side contains LDR module that absorbs the light falling from the LED’s. The detected signal further passes to the microcontroller which converts the light into data and displayed on the LCD. In addition, a buzzer is used for alarming purpose and user could also add various output to another function available. Furthermore, an IoT integration were added as to promote an alternative way of communication system rather than using radio wave frequency such as Wi-Fi connection.

CHAPTER 4

RESULT AND ANALYSIS

4.1 INTRODUCTION

In this chapter, the result of prototype on Visible Light Communication has been discussed. The project on light communication medium has conducted on constructing circuit using TinkerCAD and Proteus for the simulation, IoT Blynk for the IoT dashboard monitoring and also external serial monitor to work around on the data detection. This prototype was tested in various ways which mimics the situation for the work around in the smart home system. However, this prototype was built on small scale size to make it compact and simple.

The implementation of the prototype will use LED as a light source as well as add communication capabilities to it. The transmitted data will be digitized and then will be given to LED, turning led ON for ones and OFF for zeros. The transmission data rate must be so high that it eliminates the flicker and perceive as a constant light source to human eye.

The software and hardware implementation of the Visible Light Communication transceiver and design of the placement consideration were also discussed in detail. The experiments are conducted to identify a suitable Visible Light Communication transceiver pair, in the context of reliability and maximum communication distance. The integration of Visible Light Communication of smart home was performed with various ways.

4.2 Manchester Encoding workaround

Manchester encoding is a line coding technique in which each bit represents a transition from low to high or high to low. It is also known as phase encoding. Manchester encoding provides self-clocking, which means the clock signal can be recovered from the encoded data (Roger Forster, 2000). Because of self-clocking, this encoding technique is often used in many wireless communication technologies.

The clock rate is directly proportional to the line voltage transitions. Thus, provides clock recovery. The IEEE 802.3 standard convention of Manchester encoding is shown in Figure 4.1. Each bit is encoded as one clock cycle. Binary 0 is a transition from high to low and 1 is a transition from low to high.

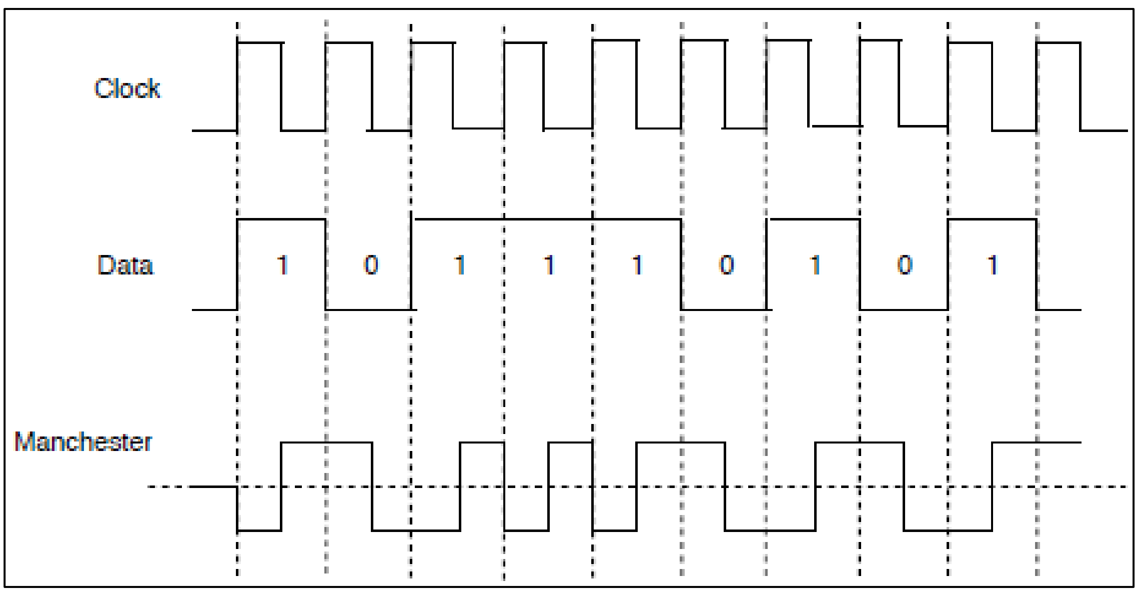

Figure 4.1: IEEE 802.3 standard Manchester encoding sample. (Roger Forster, 2000)

The transceiver uses the basic transmission and reception algorithms. The parameters shown in Figure 4.2 and Figure 4.3 are used for communication.

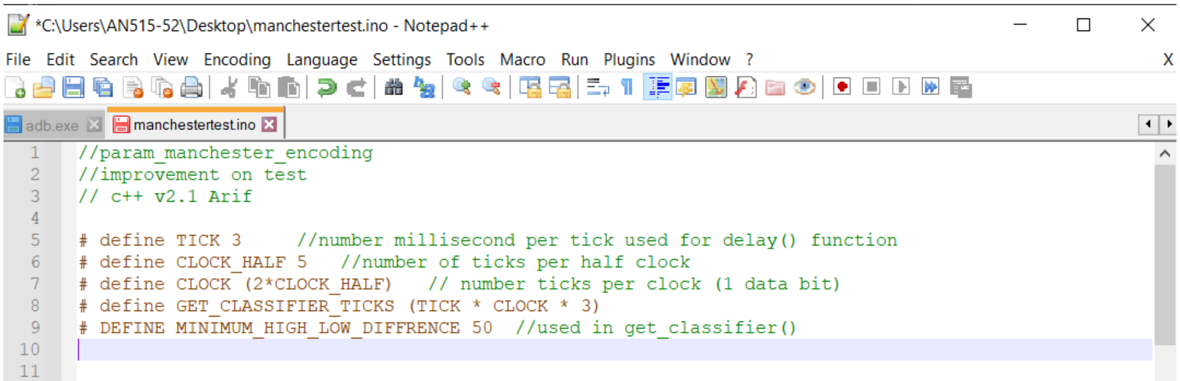

Figure 4.2: Parameters in programing Manchester Encoding.

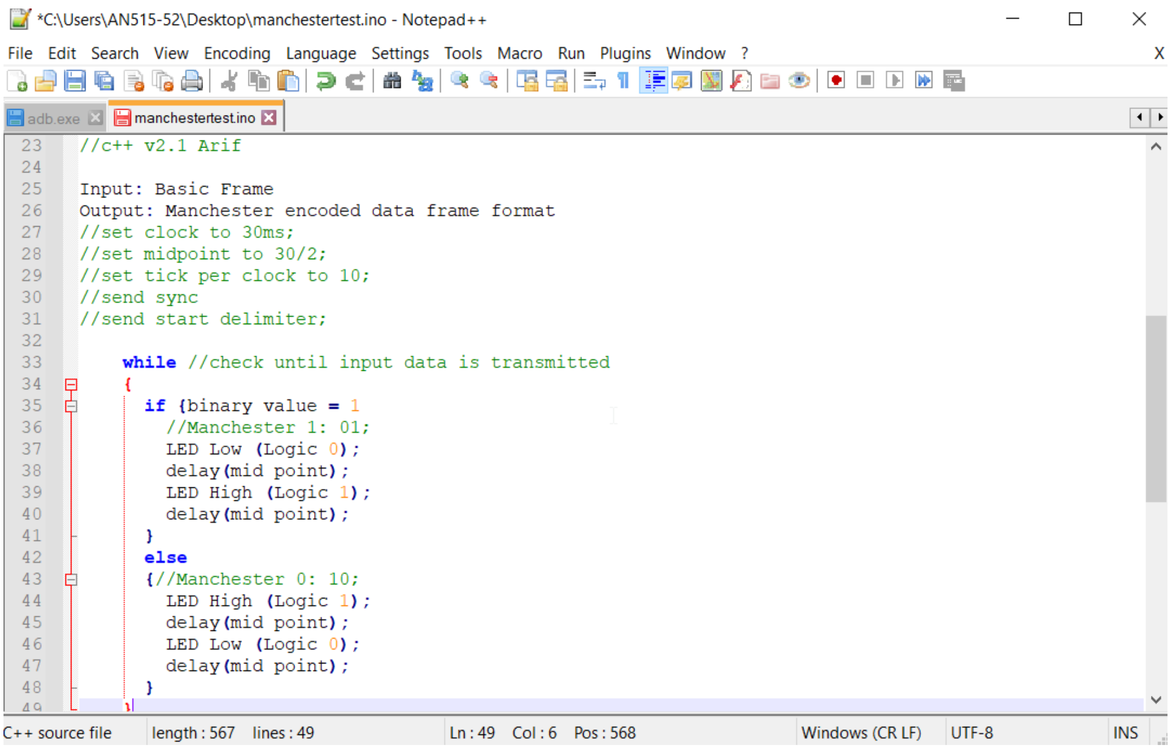

Figure 4.3: Transmission configuration program.

The CLOCK cycle contains 10 TICKs and each TICK of 3 ms. In one CLOCK cycle, one bit of data is transmitted. The classifier is calibrated using the MINIMUM HIGH LOW DIFFERENCE, which is set to 50.

4.3 Testing Parameters Hardware Communications

This section was to test related hardware component with possible data on communication distance and reliability of Visible Light Communications. The result will be discussed details on the discussion section later.

4.3.1 First Testing Matrix: Maximum Communication Distance

The objectives of this experiment are to find the maximum communication distance and to identify a suitable transceiver pair.

The LED based Visible Light Communication receiver shown in Figure 4.4 is used in this experiment. The experimental setup shown in Figure 4.4 is verified with different color LEDs as receivers and with different TICK sizes. The parameters of Visible Light Communication protocol used for building the LED based transceiver are:

- TICK =3 ms and 4 ms // number of milliseconds per Tick
- CLOCK_HALF = 5 // number of ticks per half clock
- MINIMUM_HIGH_LOW_DIFFERENCE = 3 // to get the classifier at the receiver

The LDR based Visible Light Communication transmitter is designed, as shown in Figure 4.4. The experimental setup with LDR based transceiver is also shown in Figure 4.4. This setup is tested with different color transmitting LED and LDR as the receiver. The hardware components required for this experimental setup are:

- Arduino-UNO AT Mega 328P.
- LEDs: Red, Blue, Yellow, Green, White at the transmitter side.
- LDR at the receiver end.
- 270 Ω resistor at the transmitter side and 270 Ω resistor at the receiver end.

In the first iteration, the communication distance is measured with TICK size of 3 ms. A series of iterations are performed to find the maximum communication distance. In the next instance, the TICK size is changed to 4 ms and continued with the same procedure to find the communication distance. The maximum communication is verified with different color LEDs as transceivers.

Initially, a red LED is used as a transmitter and the LDR as a receiver. The communication distance is measured with a TICK size of 3 ms. A series of iterations performed to find the maximum communication distance. The same procedure is applied for different color transmitting LEDs such as Blue, Yellow, Green, White and LDR as a receiver to find the effective transceiver pair. In the next instance, the TICK size is changed to 4 ms and performed the same process to verify maximum communication distance. The experimental results listed in Table 4.1 are evaluated in Section 4.5.1.

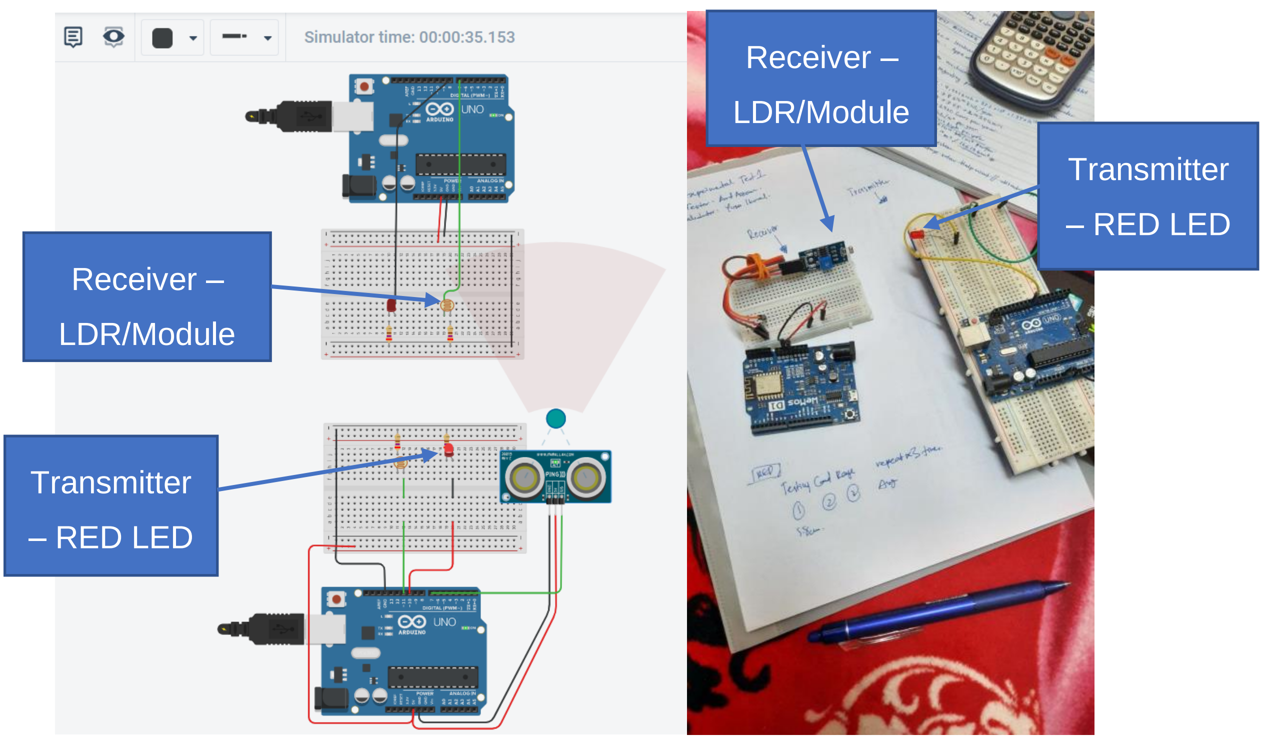

Figure 4.4: Setup of transceiver testing performed in software (TikerCAD) and hardware (Prototype) for distance test.

In another test case, an obstacle is placed between the transmitter node, LED, and the receiver node, LDR. This scenario is shown in Figure 4.5. Since the communication is based on visible light, the transmission of light gets obstructed due to the presence of obstacle between the two communicating entities. This leads failure in communication between the two nodes and the data transmitted by the transmitter is not received by the receiver. The results obtained for this test case are presented Table 4.1 and Table 4.4.

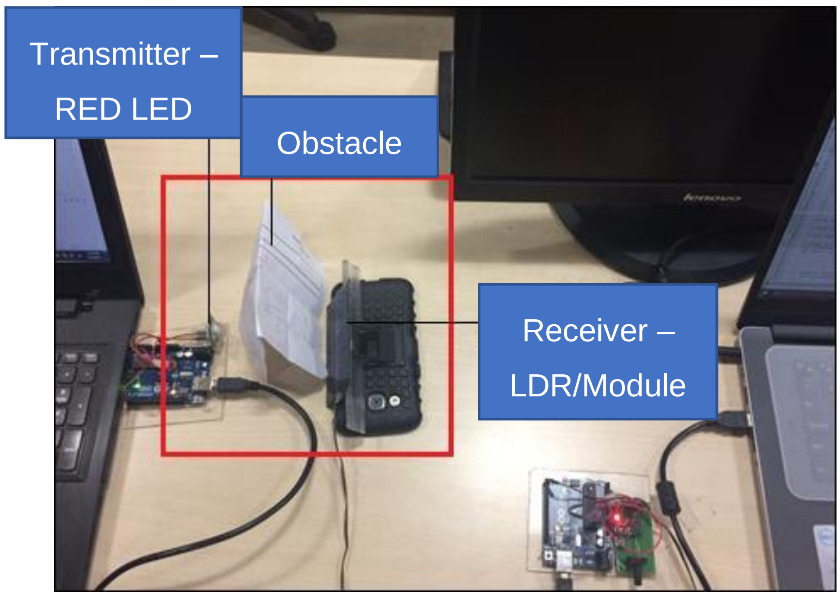

Figure 4.5: Testing transceiver blocked by an obstacle.

Table 4.1: Testing Matrix for LED Communication Distance of Visible Light Communication.

Colour of LED	**Communication Distance in (cm) with different TICK size** (*Based on single LED Transmitting on each test.)							
	3ms TICK				**4ms TICK**			
Testing Count	Test 1	Test 2	Test 3	Average	Test 1	Test 2	Test 3	Average
RED	5.8 cm	6.1 cm	6cm	6cm	17.2 cm	17 cm	17 cm	17 cm
BLUE	8.1 cm	8.1 cm	7.9 cm	8 cm	29.0 cm	29.1 cm	30 cm	29 cm
YELLOW	2.7 cm	3.0 cm	2.9 cm	2.9 cm	13 cm	13.1 cm	13 cm	13 cm
GREEN	4.2 cm	4.4 cm	4.4 cm	4.3 cm	24 cm	23 cm	23 cm	23 cm
WHITE	30 cm	30 cm	29 cm	30 cm	65 cm	68 cm	68 cm	66.5 cm

4.3.2 Second Testing Matrix: Reliability of Visible Light Communication

The aim of this testing method is to find the reliability of Visible Light Communication between two nodes, based on different communication distances, payloads and TICK sizes.

The hardware setup for this experiment is shown in Figure 4.6 and Figure 4.7. The reliability of both prototype is verified with a white LED as a transmitter and LDR as a receiver. The communication distance is varied from 5 cm to 20 cm. The protocol parameters are as follows:

- TICK=3 ms and 4 ms // number of milliseconds per Tick
- CLOCK_HALF = 5 // number of ticks per half clock
- MINIMUM_HIGH_LOW_DIFFERENCE = 50 // to get the classifier at the receiver

Initially, both transceivers are placed at 5 cm communication distance with TICK size of 3 ms. The transceiver sends 1 B payload using the information frame illustrated in programming coded in Section 4.2. The transceiver in the other end receives data. This transmission is repeated simultaneously, and the second transceiver counts on successful data reception. This procedure applied for different payloads from 1 B to 5 B.

In the next instance, the TICK size is changed to 4 ms and the communication distance is set to 5 cm. A series of iterations performed to compute the reliability of Visible Light Communication with different parameters. The reliability of the project tested with 3 ms TICK and 4ms TICK were listed in Table 4.2. These results are evaluated in Section 4.5.2.

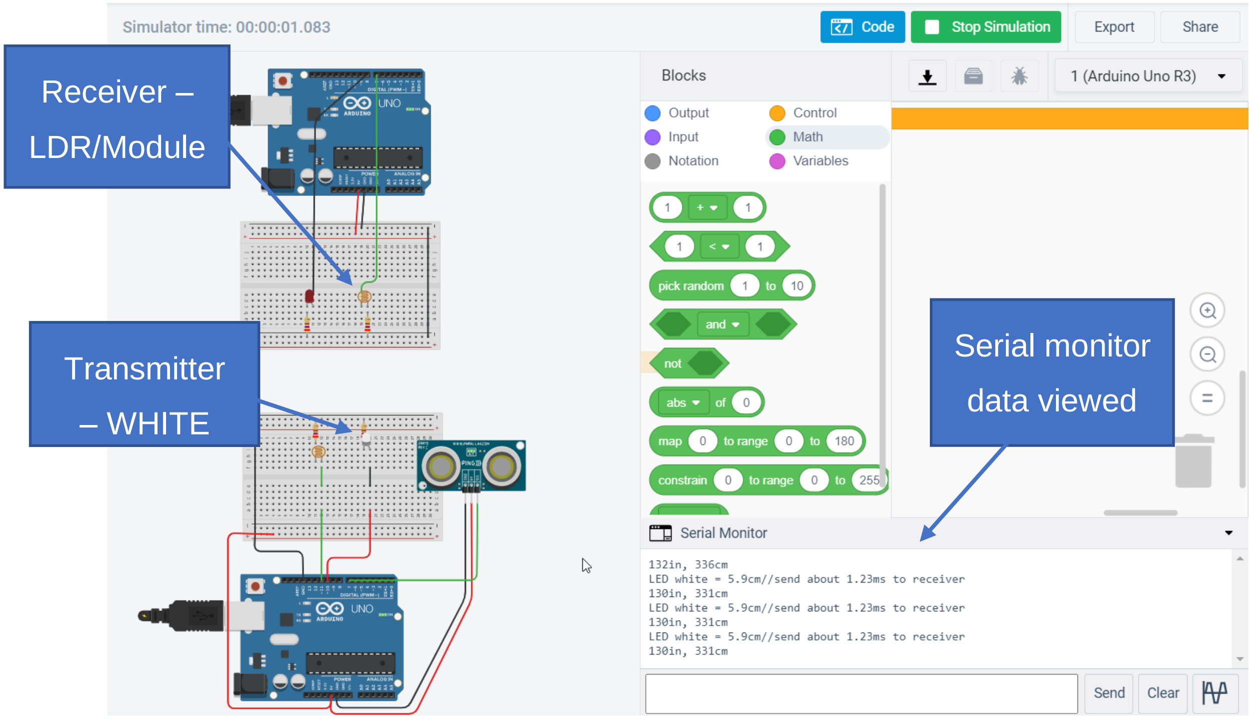

Figure 4.6: Setup configuration for software testing (reliability test).

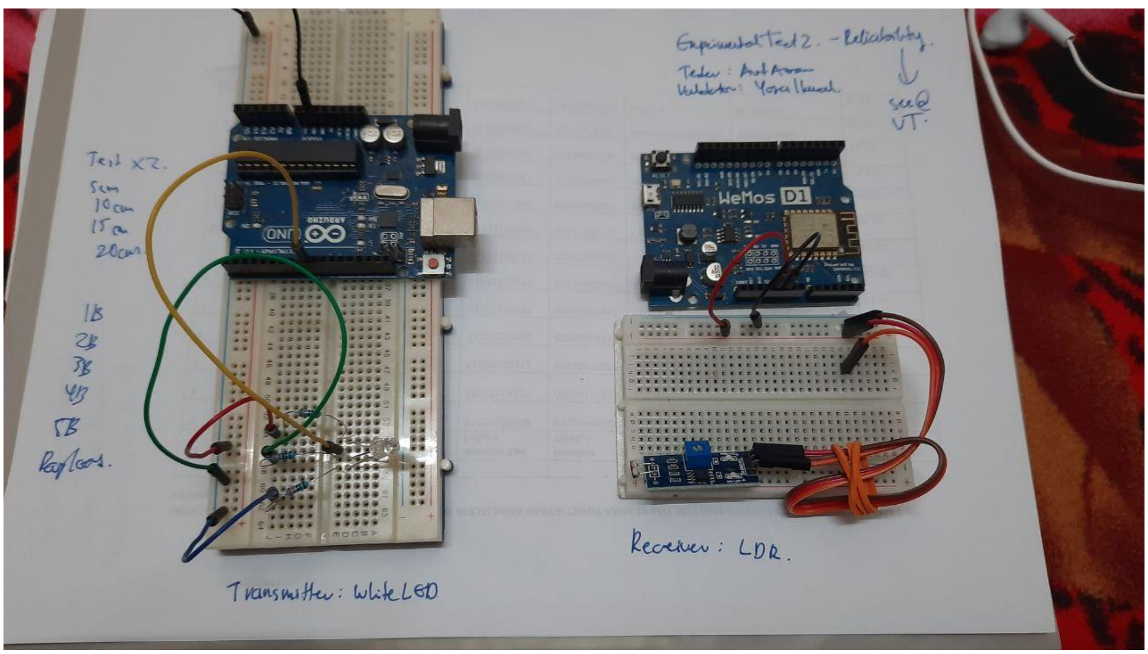

Figure 4.7: Setup configuration for hardware testing (reliability test).

Table 4.2: Testing Matrix for LED Communication Reliability of Visible Light Communication.

Payload	**Difference communication Distance in (cm) with Reliability of transmitter and receiver (WHITE LED)**							
	3ms TICK				**4ms TICK**			
Distance	5cm	10 cm	15 cm	20cm	5 cm	10 cm	15 cm	20cm
1B	99%	97%	96%	96%	99%	98%	97%	95%
2B	99%	98%	96%	96%	97%	96%	96%	95%
3B	98%	96%	95%	94%	97%	96%	95%	95%
4B	97%	96%	95%	93%	97%	96%	95%	94%
5B	97%	95%	93%	91%	96%	95%	94%	93%

*1% reduction will be counted as <= 1ms delay in the data acquired by the virtual terminal.

4.3 Testing Parameters Software Communications

4.3.1 Third Testing Matrix: IOT Blynk Distance & Reliability Communication

The main objectives of this testing parameters are to test the Visible Light Communication on LED status monitoring on data receive through LED to LDR for creating a scenery of smart home functionality.

The experiment is conducted with only using local server connected to blynk cloud connection on hardware prototype. The communication distance is varied from 100 cm to 400 cm. The prototype can be controlled remotely as the hardware connects to the blynk server via USB port attached. The hardware required for the experimental setup of prototype are:

- Arduino-UNO AT Mega 328P.
- LEDs: White at the transmitter side.
- LDR at the receiver end.
- 270 Ω resistor at the transmitter side and 270 Ω resistor at the receiver end.
- Smartphone with Blynk Apps
- USB Connector Type B for establishing connection to blynk server from microcontroller.

Initially blynk apps were setup in the smartphone which allows user to design own dashboard setups. The blynk apps were simple and easy to use because the software does not use much programming on monitoring the virtual sensors declaration to the hardware. The procedure of the testing matrix is to make sure the synchronization between hardware and software of IoT is stable and doesn't take to much delay on the data displayed.

The IOT Dashboard will features some of functionality of displaying time, push button for checking circuit functionality of LED, display brightness of LED and notification of microcontroller. This will be accessed and tested on the testing matrix Table 4.3.

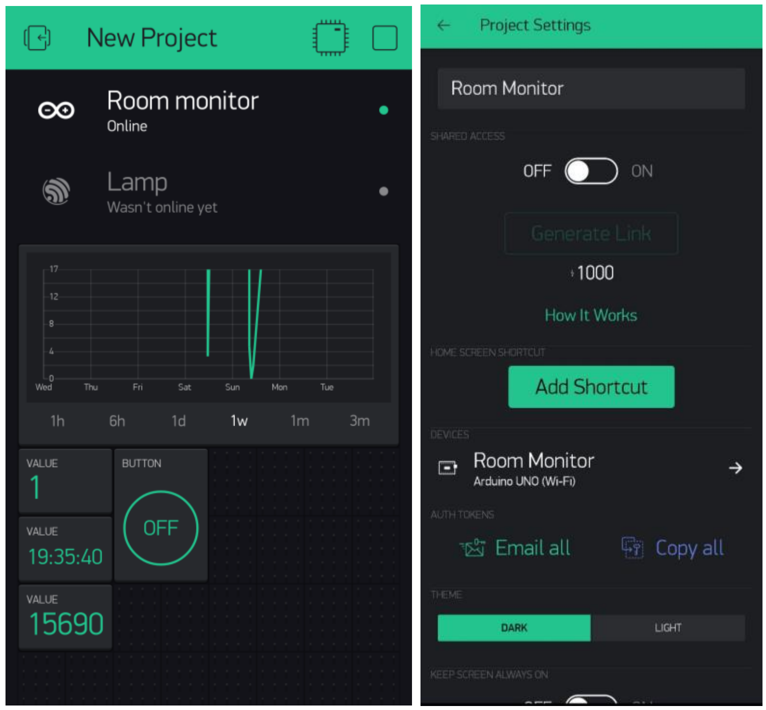

Figure 4.8: Simple dashboard IOT of Blynk for testing the distance & reliability of communication.

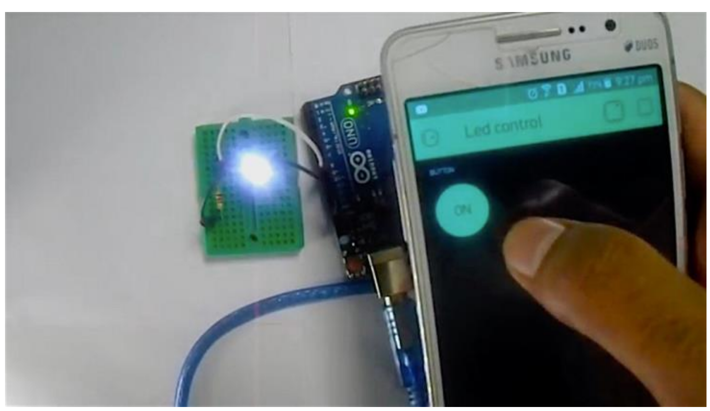

Figure 4.9: Testing with real prototype of certain parts of LED and Microcontroller of Visible Light Communication.

Table 4.3: Testing Matrix for Distance & Reliability Communication Distance with IOT Blynk integration

White LED	Difference communication Distance in (cm) with Reliability of transmitter and receiver							
	3ms TICK				4ms TICK			
Distance	100cm	200cm	300 cm	400 cm	100cm	200 cm	300cm	400 cm
1B	99%	98%	95%	94%	99%	98%	97%	95%
2B	99%	97%	95%	93%	98%	95%	95%	94%
3B	96%	94%	93%	92%	96%	95%	94%	94%
4B	95%	94%	92%	92%	93%	92%	92%	91%
5B	94%	93%	92%	91%	91%	90%	90%	89%

*1% reduction will be counted as <= 1ms delay in the data acquired by the virtual terminal.

4.4 Experiments on Visible Light Communication Project

This section was to test related hardware component with possible data on communication distance and reliability of Visible Light Communications. The result will be discussed details on the discussion section later.

4.4.1 Design Prototype scale.

4.4.1.1 Design with LED Lamp and transceiver installed.

The smart home has different material flow resources such as lighting LED Lights, Visible Light Communication receiver and transmitter and IoT integration as shown in Figure 4.10. Most of smart home do rely on the wireless communication medium such as Wireless Fidelity (Wi-Fi) or Bluetooth medium. Thus, this alternative electromagnetic wave spectrum based on visible light will open new possibilities on functionality of IoT workarounds. The smart home based Visible Light Communication have different data transmit through different location of lamp with a receiver attach to the core of microcontroller of At-Mega 328P.

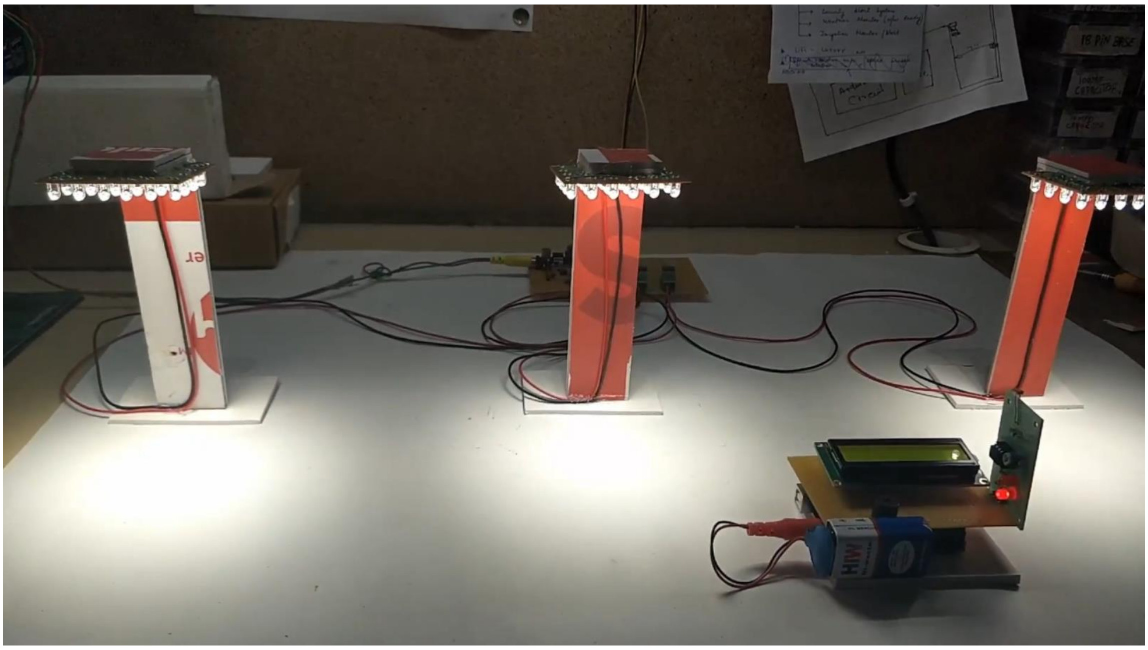

Figure 4.10: Different pole LED (transmitter) with receiver circuit

4.4.1.2 Receiver node Visible Light Communication

The receiver node consists of a controller, Light Diode Resistance, LED and LCD Display for display the output source of the Visible Light Communication. The receiver node will be collecting data under the transmitter node and process the information data to the LCD Display. The workaround of the decode parts of the programing is configured with Manchester Encoding. The receiver will be integrated with IoT integration for monitoring functionality.

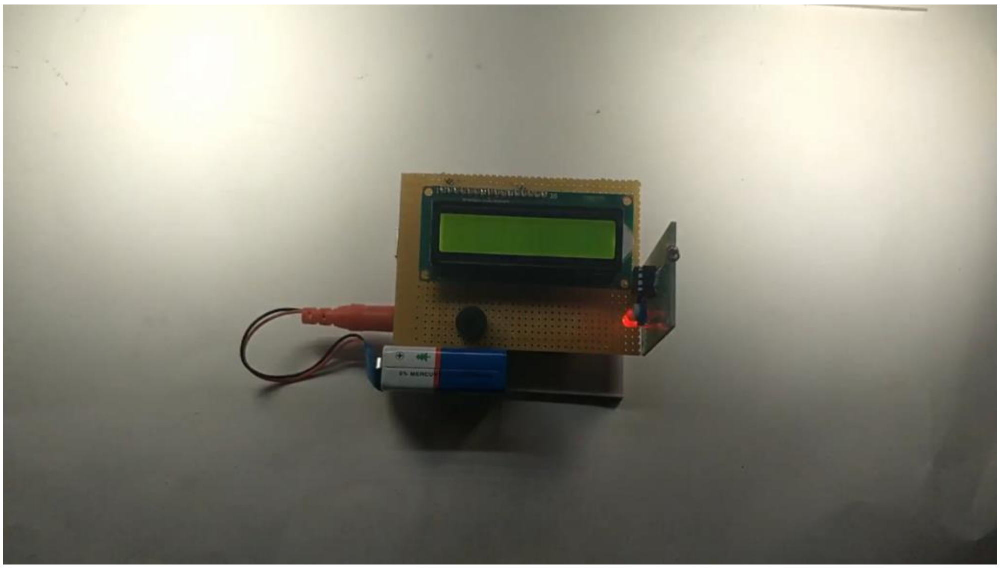

Figure 4.11: Prototype of receiver node of Visible Light Communication

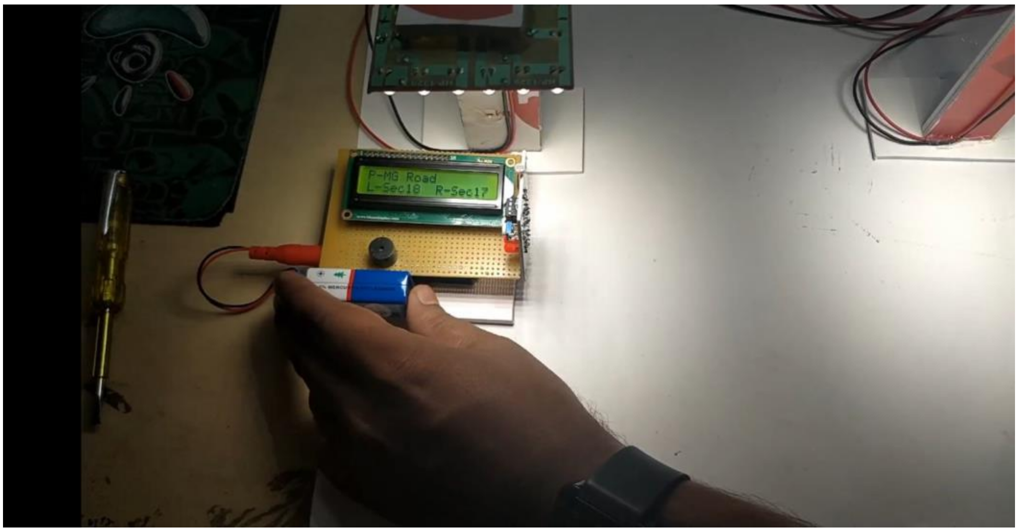

Figure 4.12: Receiver under LED transmitter shows data on LCD Display.

4.4.1.3 Transmitter node Visible Light Communication

The transmitter node was combined in another microcontroller which consist of White LED as the medium for transfer of data, Arduino ATMega 328P as the core, battery, and some component holders. The LED transmitter node will be built on 3 different output which means there are three different transmitter that will tested on. The connection was shown in Figure 4.12 and Figure 4.13.

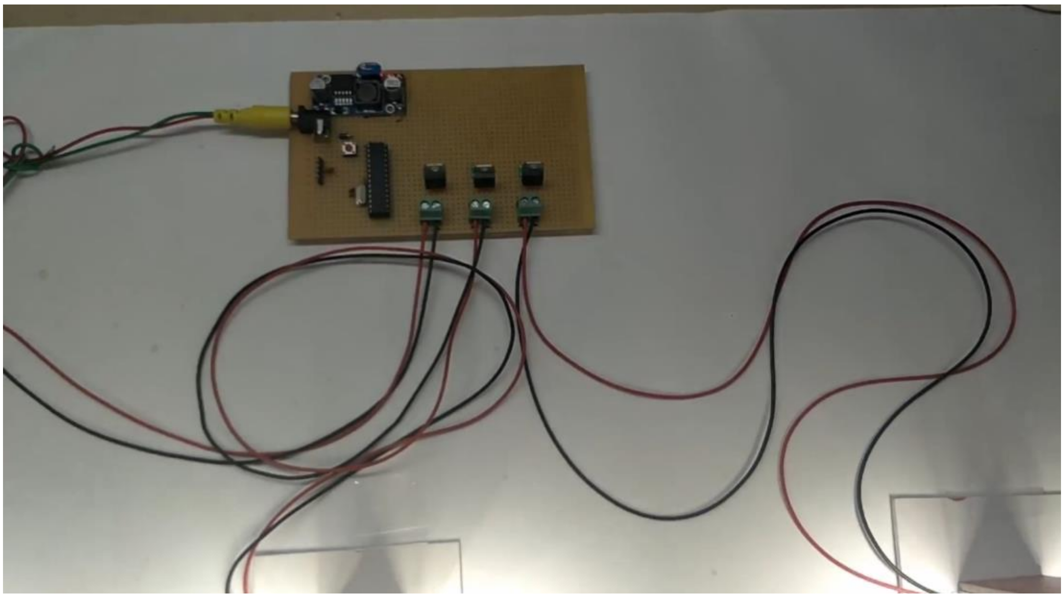

Figure 4.13: Circuit of transmitter node constructed on the breadboard.

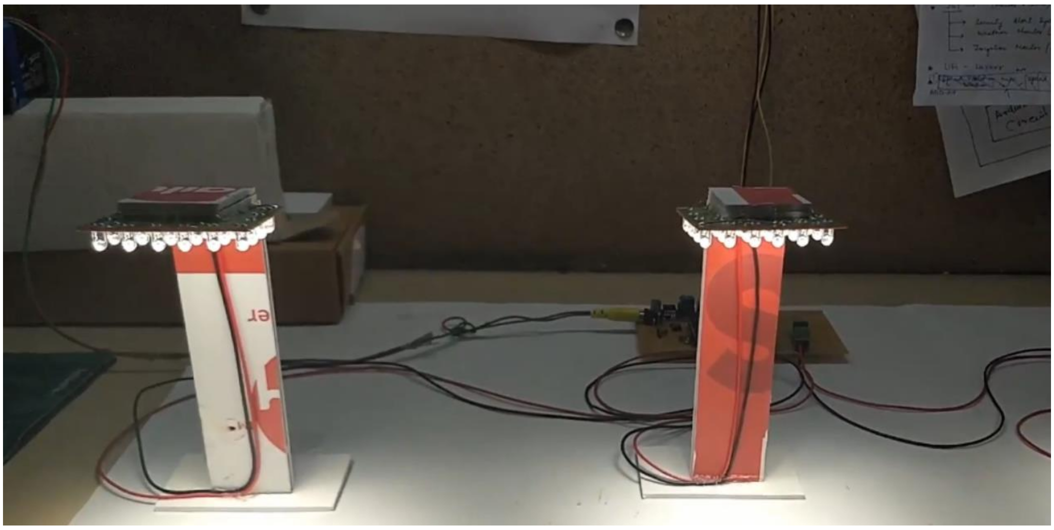

Figure 4.14: Transmitter LED pole lamp of Visible Light Communication.

4.4.2 Transmission of Visible Light Communication via IOT Integration

The transmission and reception of data through VLC is demonstrated in Figure 4.10. Transmission of data from input device takes place when the data is sending from the transmitter LED pole to receiver node of the Visible Light Communication as designed earlier. The transmitted information can be seen in Figure 4.12, and the received information can be seen in Figure 4.15.

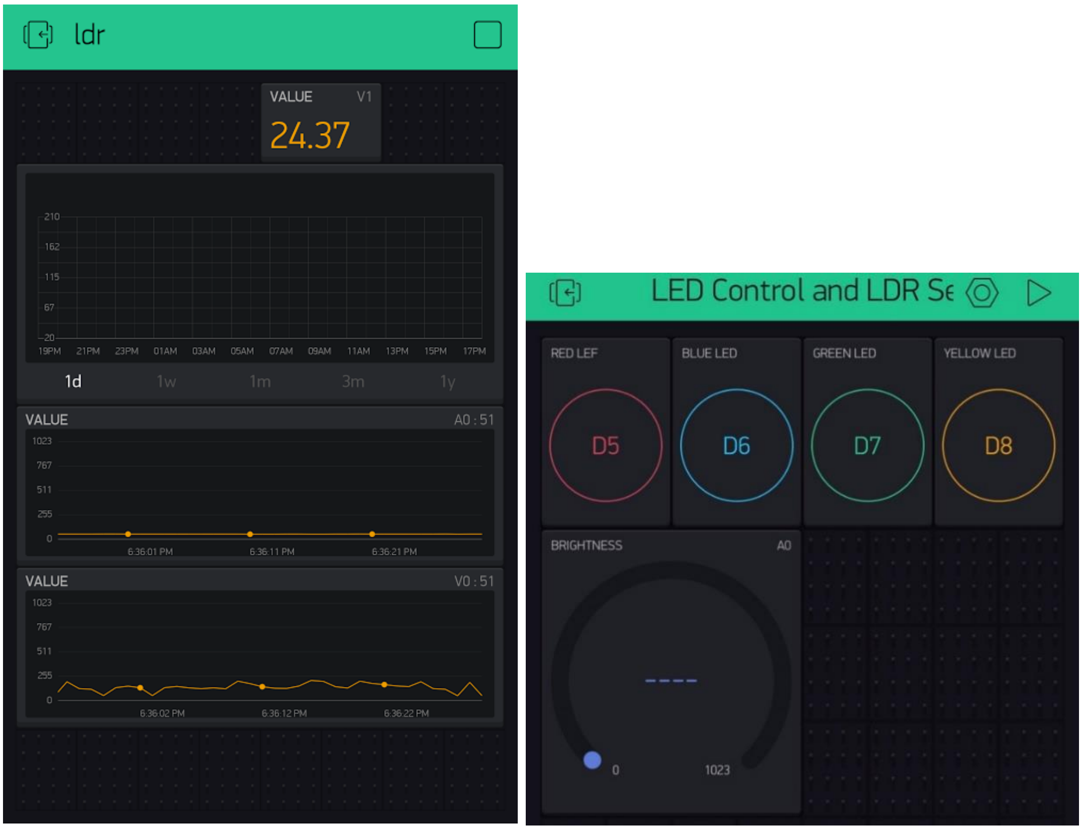

Figure 4.15: Blynk IOT Dashboard of LDR Status.

Based on testing matrix tested, there are many options to be considered on placement of the Visible Light Communication. This project basically designed for indoors as there were not much ambient or noise resulted in poor data collected. As for now, the Visible LIGHT Communication were conducted in a room with acceptable light source. This may be improved by conducting bigger light source or higher penetration lighting such as Lasers. However, there were no significant research on using different light source as a medium for Visible Light Communications rather than regular LED Lightings.

4.4.3 Experiment Results

Table 4.4: Testing Visible Light Communications

NO	TEST DETAILS	METHOD	RESULT	STATUS
1	Checking prototype status	Power up prototype with battery and USB powered source	Prototype both transmitter and receiver initialize well & functioning	PASSED
2	LED data transmit	Placed receiver under LED (transmitter source)	Short word displayed on LCD Display	PASSED
3	IOT Integration	Connect microcontroller via Blynk to monitor LED status	LED status were shown on Blynk on the receiver node via LDR	PASSED
4	Blocking transmitter source	Add a obstacle nearby	Data not shown on LCD Display	PASSED
5	Different scene effect to transmitter and receiver	Place under normal lightings indoor	Data shown a bit delay since having ambient light source	Smaller scope will specify the uses of VLC in early stage

6	Battery duration for power supply	Placed with receiver for standalone prototype	Can withstand for long period as the transmitter node only use low power 5V, 1A max	PASSED
7	Testing other microcontroller as a part of the transmitter and receiver node	Adding support for NodeMCU ESP 8266	Not much significant details acquired, but powerful core will much having more transmission speed for the project	PASSED but can be improved
8	Flicker on LED Transmitter	Observe on LED Transmitter behaviour	Acceptable, a bit flicker since the data were transmitted to the receiver node	PASSED but can be improved

4.5 Discussion

In this section, the experimental results and the parameters of the Visible Light Communication are evaluated to identify the good transceiver pair and communication reliability. Integration of VLC communication in smart home is evaluated.

4.5.1 Relationship between Distance and Reliability of Visible Light Communication

4.5.1.1 Maximum Communication Distance

The maximum communication experiment discussed in Section 4.3.1 provides the experimental results of both LED based VLC transceiver and LDR based VLC transceiver.

The LED based VLC transceiver gives a maximum communication distance of 2 cm with 4 ms TICK and 1 cm with 3 ms TICK. This experiment also states that only blue color LED provides reliable communication, and other color LEDs failed to communicate. As, this experiment results in very smaller communication distances, one more experiment is conducted with LDR based VLC transceiver. This results in higher communication distances, LDR is used as a receiver which is sensitive to different light intensities. So, different color LEDs used as transmitters and verified the maximum communication distances. The graph is shown in Figure 4.16 illustrates the comparison of maximum communication distance with different transmitting LEDs and TICK sizes. The protocol parameter TICK size also has a major impact on the maximum communication distance. As shown in Table 4.1, the white LED as a transmitter and LDR as a receiver gives a distance of 30 cm with a TICK size of 3 ms. The maximum communication distance achieved was 68 cm with a TICK size of 4 ms. From this experiment, it is clear that higher TICK size results in longer communication distances.

From the graph shown in Figure 4.16, the communication distances of other LEDs show that the white LED as a transmitter and LDR as a receiver can be used for the best design of Visible Light Communiaction transceiver.

4.5.1.2 Reliability of the Visible Light Communication protocol

Following the first experiment, this experiment gives the reliability of the protocol, which plays a major role in communication. The reliability is verified between two nodes with the rate of successful reception of data explained in Section 4.3.2. The comparison of reliability with different parameters are listed in Table 4.2. The graphs are plotted from the tables. The graph shown in Figure 4.17 illustrates the increase in payload results in loss of data. The reliability of 5 B payload is less compared to 5 B payload with a communication distance of 5 cm.

The graph shown in Figure 4.18 explains the increase in distance with constant payload decreases the reliability. The reliability of 3 B payload with different communication distances is explained in the graph. The graph illustrates the influence of TICK size on reliability. If the communication distance is more,then 4 ms TICK size gives slightly better reliability.

The graph is shown to provide the comparison data of reliability with different payloads, communication distances and TICK sizes. It is shown that the TICK size does not have any significant effect on reliability for smaller communication distances. The reliability is less with more payload and longer communication distances.

After carefully examining all graphs discussed in this section, it is concluded that 5 cm communication distance results in 96% to 99% of reliability with different payloads and TICK sizes. The communication distance effects the reliability, but the protocol provides slightly better reliability for longer communication distances with 4 ms TICK size. The TICK size impacts more on communication distance not significantly on reliability. So, 3 ms TICK size can be used as CLOCK parameter for faster communication.

4.5.3 Performance Evaluation of Visible Light Communication

In this section, the performance of VLC protocol is evaluated based on the transmission time of frame. Initially, the transmission time is calculated with different parameters and information frame as shown in Figure 4.1, 4.2, and 4.3 is used for transmission. The parameters of VLC protocol to compute the time required to transmit 1 B of payload with overhead are as follows:

- TICK(T) = 3 ms and 4 ms and 5 ms // number of milliseconds per Tick
- CLOCK_HALF(c) = 5 // number of ticks per half clock
- CLOCK(C) = (2 * CLOCK_HALF) //number of ticks per clock (1 bit of data)

The calculation of transmission time for 1 B payload is shown below:

$$T = 3 \text{ ms} \tag{4.1}$$

$$c = 5 \times 3 \text{ ms} \tag{4.2}$$

$$= 15 \text{ ms} \tag{4.3}$$

$$C = 2 \times c \tag{4.4}$$

$$= 30 \text{ ms} \tag{4.5}$$

$$1 \text{ bit} = 30 \text{ ms} \tag{4.6}$$

$$\Rightarrow 1 \text{ B} = 8 \times 30 \text{ ms} \tag{4.7}$$

$$= 240 \text{ ms} \tag{4.8}$$

$$8 \text{ B} = 8 \times 240 \text{ ms} \tag{4.9}$$

$$= 1920 \text{ ms} \tag{4.10}$$

The payload data is encoded in the information frame. The frame is composed of 8 B to transmit 1 B of payload data. It requires 1920 ms from Equation 4.10 to transmit 1 B payload including the overhead of information frame. Similarly, the transmission time for different payloads and TICK sizes are calculated and listed in Table 4.5. From the table, the graph shown in Figure 4.19 is plotted.

With smaller TICK size the transmission time is less compared higher TICK size for the same amount of data transmitted. The output is calculated from the time taken to transmit one bit of binary data. From Equation 4.11 time taken to transmit one bit data is 30 ms.

Table 4.5: Transmission time for different payloads and TICK sizes.

Payload	Transmission time with different TICK sizes	
	3ms TICK	4ms TICK
1B	1920ms	2560ms
2B	2160ms	2880ms
3B	2400ms	3200ms
4B	2640ms	3520ms
5B	2880ms	3840ms

4.5.3 Experimental Analysis by graph

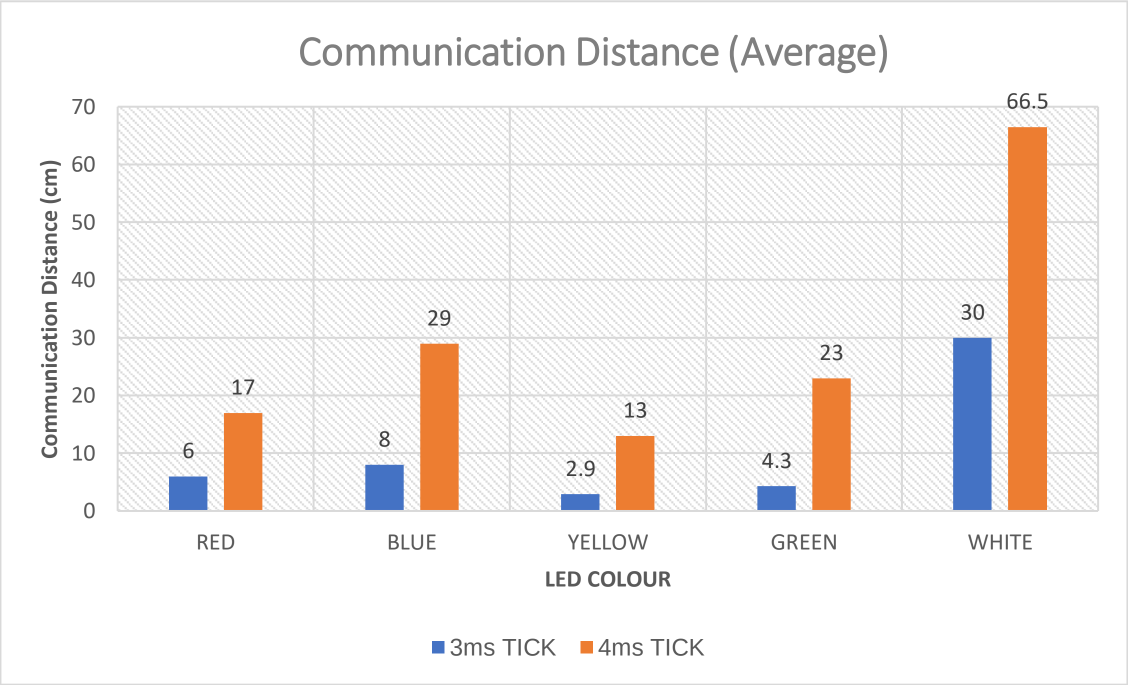

Figure 4.16: Bar chart for average LED Communication Distance of Visible Light Communication 3ms & 4ms.

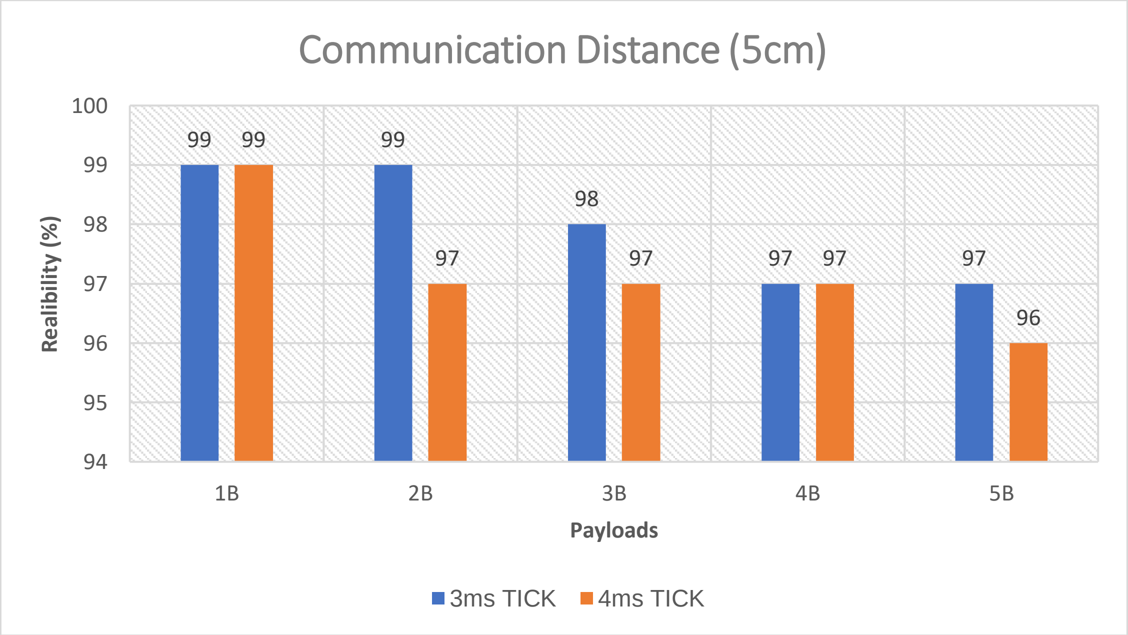

Figure 4.17: Reliability with different payloads and constant communication distance

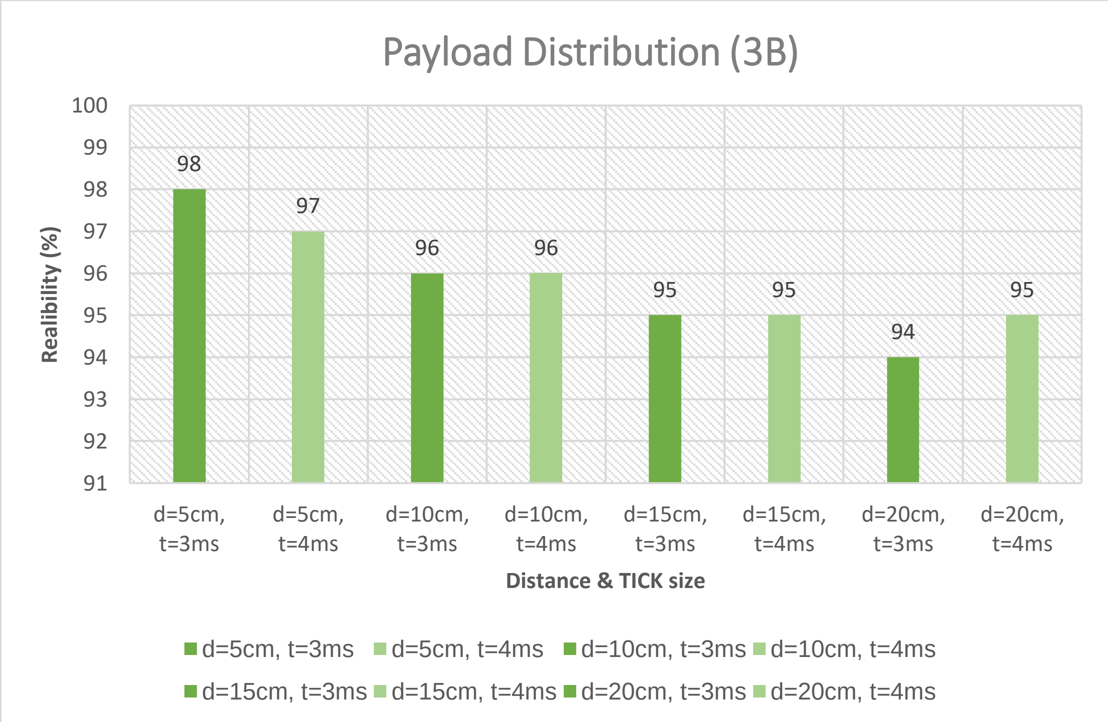

Figure 4.18: Reliability with different communication distance and constant payloads.

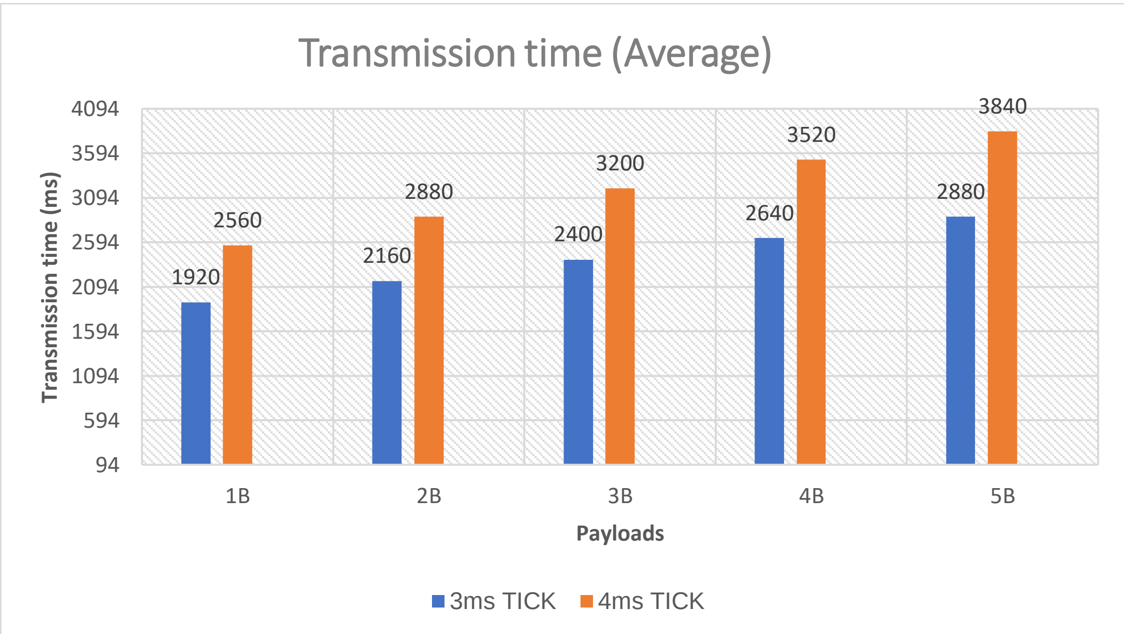

Figure 4.19: Transmission time with different TICK sizes.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will conclude the implication and result obtained from simulations that has been carried out to achieve the objectives of the research. Findings of the Visible Light Communications from Chapter 4 by implementing various testing matrix for the transceivers which are maximum distance, reliability and IoT integration provide an important data which can contribute for further research about visible light technology uses. Aside from that, based on Chapter 4, some recommendations are suggested for future improvement of the study that concern about Visible Light Communications.

5.2 Conclusions

The goal of this thesis work was to design a robust wireless communication protocol for the smart home by using visible light functionality as the light is still on the range of electromagnetic frequency. This was achieved by setting various objectives based on VLC transceiver design.

The conceptual model was designed based on the master-slave principle with modular structures, as shown in Figure 4.10. Next, the Visible Light Communication frame format was derived from the Manchester encoding and OOK modulation technique (Roger Forster, 2000). This protocol was designed using minimal functionalities and the software implementation was performed using C++ on Arduino UNO 2560 controller board. The VLC transceiver was designed with LED as a transmitter and LDR as a receiver. 9 V batteries and USB powered source are used to supply the modules. The component holders are designed with some perspex plastic and cardboard for the LED light pole.

Once the entire setup was made ready with all the software and hardware components, experiments were performed. Based on the experimental results, the Visible Light Communication was evaluated. The maximum communication distance achieved was 68 cm with a white LED as transmitter and LDR as a receiver. The maximum reliability is achieved with the optimal parameters of VLC protocol. The reliability of the communication was achieved as 99% highest and 96% lowest with constant distance communication. The evaluation of this project gives the best practical experience for setting up the smart home functionality in future works.

Last but not least, Visible Light Communication can be adaptable for the smart home uses. This communication can be implemented in real-time applications. VLC is inexpensive and the hardware implementation and setup is straightforward. In this report, the communication speed achieved is less compared to the actual speed of VLC, which is in terms of GB/s as the speed can be increased with high-speed processors. However, the communication speed is sufficient for this type of the project based on the available resource planning.

5.3 Recommendations

As of now the Visible Light Communication protocol was successfully integrated in a smart home based model. For further research, one can explore in various areas of the proposed field. For instance, The routing algorithm can be improved by implementing dynamic routing techniques, the communication speed can be increased by choosing a controller which provides high ADC clock. The error correction and re-transmission of data to make the communication more robust and efficient, the designed protocol can be extended in the other model that can be more superior than the existing works.

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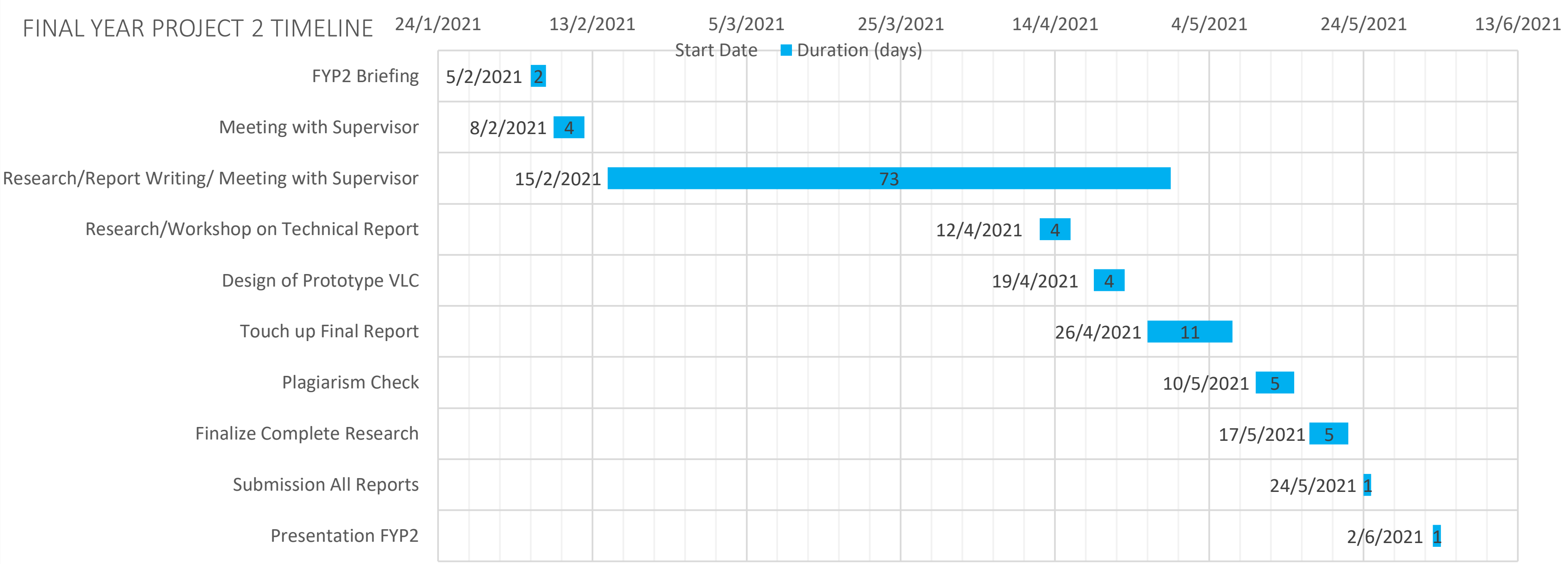
APPENDIX A

GANTT CHART



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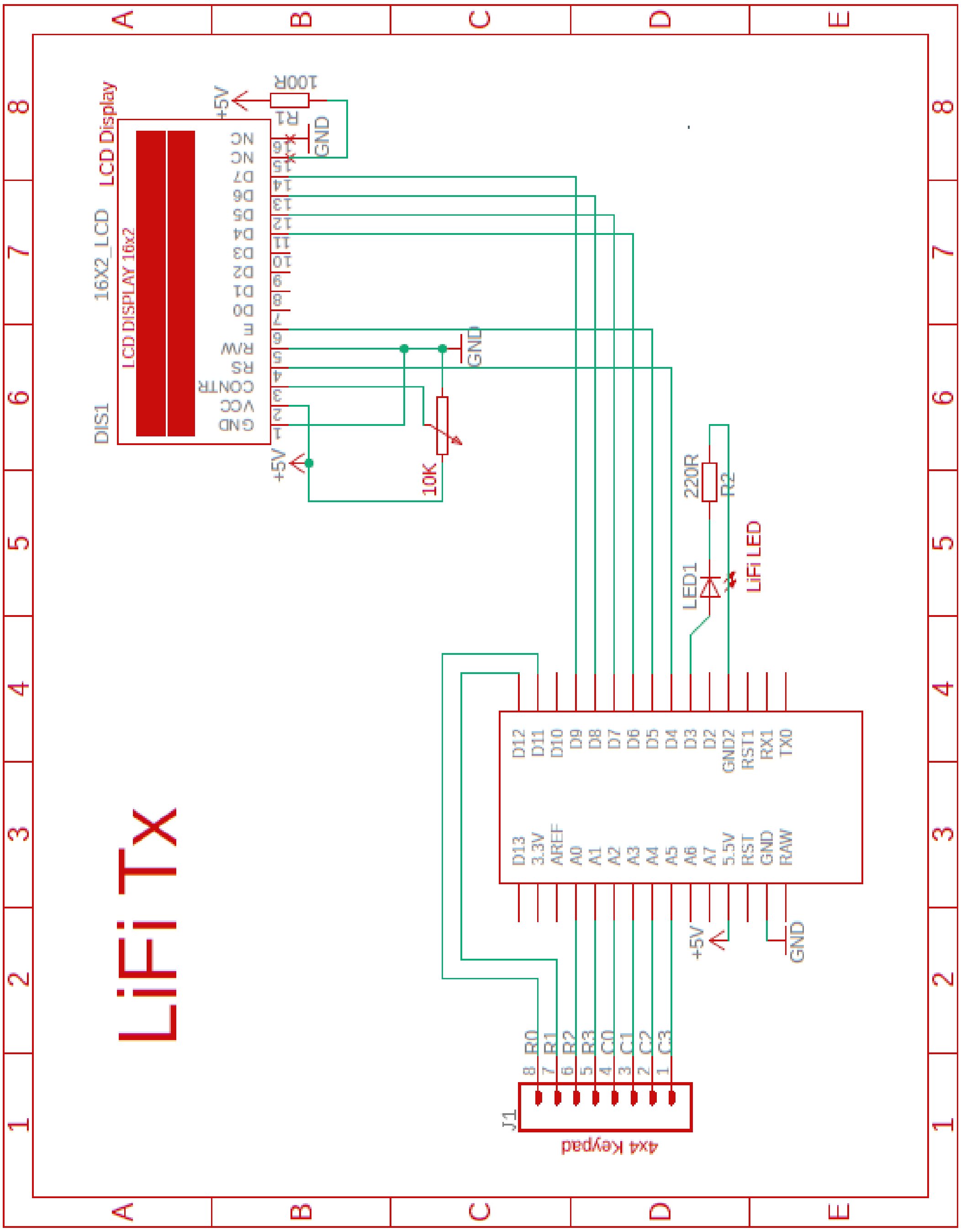
Start Date	2/6/2021	24/5/2021	17/5/2021	10/5/2021	26/4/2021	19/4/2021	12/4/2021	15/2/2021	8/2/2021	5/2/2021
Duration (days)	1	1	5	5	11	4	4	73	4	2

APPENDIX B

VISIBLE LIGHT COMMUNICATION TRANSMITTER SCHEMATICS



APPENDIX C

VISIBLE LIGHT COMMUNICATION TRANSMITTER CODE

```
#include <SoftwareSerial.h>

#include <LiquidCrystal.h>

#include <Keypad.h>

LiquidCrystal lcd(4,5,6,7,8,9);

//FOR TESTING PURPOSES

const byte ROWS = 4;

const byte COLS = 4;


char hexaKeys[ROWS][COLS] = {

  {'1','2','3','A'},

  {'4','5','6','B'},

  {'7','8','9','C'},

  {'*','0','#','D'}

};

byte rowPins[ROWS] = {11,12,A0,A1};

byte colPins[COLS] = {A2,A3,A4,A5};

SoftwareSerial GSerial(2,3);

Keypad customKeypad = Keypad( makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);

char keycount=0;

char code[5];



void setup() {

  delay(1000);

  Serial.begin(9600);

  Serial.println("Keyboard Test:");

  GSerial.begin(400);

  lcd.begin(16, 2);

  // Print a message to the LCD.

  lcd.setCursor(0, 0);

  lcd.print(" LiFi - Wireless");

  lcd.setCursor(0, 1);

  lcd.print(" Communication  ");

  delay(3000);

  lcd.clear();

  lcd.setCursor(0, 0);

  lcd.print(" using Light    ");

  lcd.setCursor(0, 1);

  lcd.print(" TX TESTING ..  ");

  delay(3000);

  lcd.clear();
```

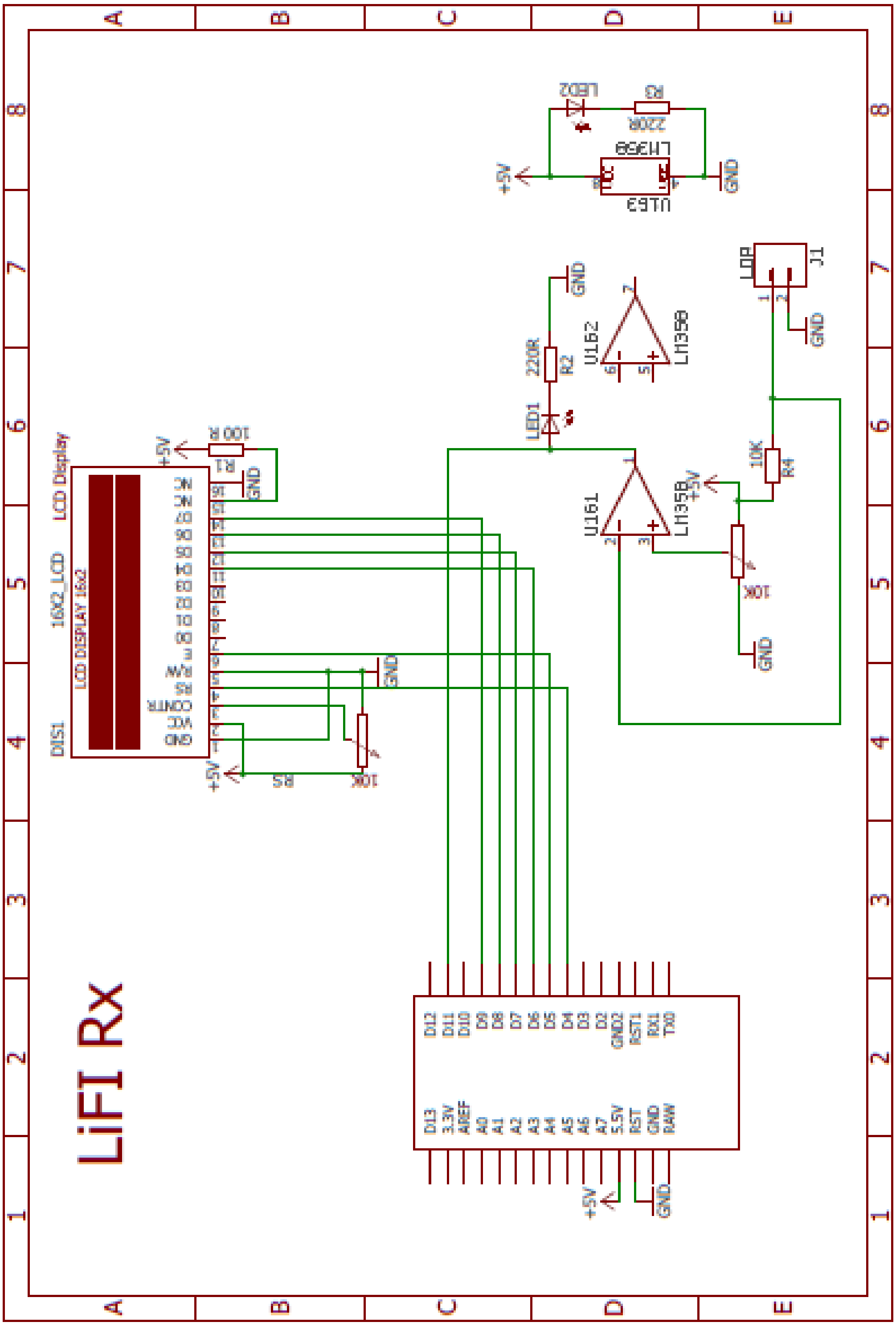
```
  lcd.setCursor(0, 0);
  lcd.print("  By ARIFAZAM  ");
  lcd.setCursor(0,1);
  lcd.print("    V1.5    ");
  delay(3000);
  lcd.clear();
  GSerial.print('&');
}

void loop()
{
  char customKey = customKeypad.getKey();
  if(customKey && (customKey !='='))
  {
    if (customKey == '#')
    {
      GSerial.print('^');
      lcd.setCursor(0, 1);
      lcd.print("                ");
      lcd.setCursor(0, 1);
    }
    else if (customKey == '*')
    {
      GSerial.print('&');
      lcd.clear();
    }
    else
    {
      // otherwise, just print all normal characters
      Serial.print(customKey);
      GSerial.print(customKey);
      lcd.print(customKey);
    }
  }
}
```

//QR CODE ready to tinker//

APPENDIX D

VISIBLE LIGHT COMMUNICATION RECEIVER SCHEMATICS



APPENDIX E

VISIBLE LIGHT COMMUNICATION RECEIVER CODE

```
#include <SoftwareSerial.h>
#include <LiquidCrystal.h>
// FOR TESTING PURPOSES
LiquidCrystal lcd(4, 5, 6, 7, 8, 9);
SoftwareSerial GSerial(11,12);
char rec=0;

void setup()
{
  Serial.begin(9600);
  GSerial.begin(400);
  lcd.begin(16, 2);
  lcd.setCursor(0, 0);
  lcd.print(" LiFi - Wireless");
  lcd.setCursor(0, 1);
  lcd.print(" Communication  ");
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" using Light    ");
  lcd.setCursor(0, 1);
  lcd.print(" RX TESTING ..  ");
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("  By ARIFAZAM  ");
  lcd.setCursor(0,1);
  lcd.print("    V 1.5   ");
  delay(3000);
  lcd.clear();
}

void loop()
{
  if(GSerial.available() != 0)
  {
    rec = GSerial.read();
    if(rec=='^')
    {
      lcd.setCursor(0, 1);
      lcd.print("                ");
      lcd.setCursor(0, 1);
    }
    else if(rec=='&')
```

```
    {
      lcd.clear();
    }

    else
    {
      Serial.print(rec);
      lcd.print(rec);
    }
  }
}
```

// QR CODE ready to tinker//

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