Original Research Article

DESIGN AND IMPLEMENTATION OF ARDUINO LIGHT FIDELITY HOME AUTOMATION SYSTEM

Abstract: Arduino based home automation system is envisage in this work using the principle of light fidelity. Light Fidelity (Li-Fi) is the fastest means of wireless communication which uses visible light to transmit data/signals between devices and is one such concept that is gaining momentum to become the possible alternative solution for overcoming the crowded radio spectrum for wireless communication system. In this paper a simple prototype of arduino Li-Fi based transmitter and receiver was designed and implemented. The Arduino transmitter processes and sends out visible light signal emitted from white LED bulb when a functional pushbutton is pressed and the Arduino receiver receives and process the signal and acts to switch ON or OFF the connected household appliances. The system was made using readily available materials and the transmitter and receiver can communicate up to a maximum distance of 41cm.

Keyword: Visible Light Communication (VLC), Light Fidelity (Li-Fi), Light Emitting Diode (LED), Arduino Platform, Automation, Home Appliances

1. INTRODUCTION

The idea for an electronic remote control, which worked wirelessly by shining a beam of light onto a photoelectric cell, came up in the United State in 1955 (Woodford, 2015). Years ago some remote control made use of wires, but modern remote control now works based on wireless communication. This allows information to be exchanged between two devices without the use of wire or cable (Ahmed *et al*. 2013). Remote control has continually evolved and advanced over recent years to include Infrared (IR), Radio frequency, Bluetooth connectivity, motion sensor-enabled capabilities, voice control, GSM and ZigBee. Light Fidelity (Li-Fi) is the fastest means of wireless communication which uses visible light to transmit data/signals between devices and is one such concept that is gaining momentum to become the possible alternative solution for overcoming the crowded radio spectrum for wireless communication system. The signal is conveyed by turning the LED on and off through on-off keying (Amplitude Shift Keying) technique. The idea of light fidelity (Li-Fi) was coined by German physicist, Professor Harald Hass of the University of Edinburgh in his 2011 TED Global Talk. According to Hass, the light, which he referred to as ''D-light" (i.e data through illumination) can be used to produce data rates higher than 10 megabits per second which is much faster than our average broadband connection (Harald *et al*. 2015)

The recent advancements in data/signal wireless transmission employing light-emitting diodes (LEDs) are due to their unique possibility to encode data at speeds of tens of Gb/s. Therefore visible light communications (VLC) and light fidelity (Li-Fi) emerged as integral components of fifth-generation (5G) networks and beyond, as well as the internet-of-things (IoT) era (Serafimovski, 2018), where optimal encoding of binary information into the structure of light is achieved. The IoT can be defined as the process of connecting everything around us to the Internet and manage their interactions (Khan *el at*. 2012).Internet of Things (IoT) is the main enabler of controlling and monitoring devices remotely. These systems are very useful especially to help handicapped and aged people to use their home appliances in an easy and smarter way (Sagar & Kusuma, 2015). With the development of the Internet of things (IoT), an increasing number of devices can access the Internet. "For 2020, the installed base of Internet of Things devices is forecast to grow to almost 31 billion worldwide (Nordrum, 2016). In home automation systems, many devices and software applications are integrated together to achieve the automation process (Javale*el at.* 2013).

Moreover the use of radio frequency based communication system for data transmission and communication between terminals proves fatal thereby causing vast destruction in environment like oil industry, hospital, and aircraft cabins (Park &barry, 1995). To avoid such situation light can be used as carrier wave for data and or signal transmission and reception. Li-Fi technology supports both illumination and wireless communication using an LED based on intensity modulation/direct detection technique, a huge amount of unregulated bandwidth is available at visible light frequencies. The visible spectrum is the portion of the electromagnetic spectrum having wavelengths from about 380 nm to 780 nm with frequency range corresponding to 385 - 789 THz (Arnon, 2012). Its operation is very simple. When the optical transmitter LED is "ON", the photodiode at the receiver detect and noted a binary logic one (1) and when the LED is "OFF" the photodiode detect and noted a binary logic zero (0). LED's transmit binary information, with the higher flickering speed of LED's one can accomplish higher information rates. Light fidelity technology has a great potential in the field of wireless signal transmission and reception with increased accessible spectrum, low latency, bi-directionality, speed, efficiency and security. Light fidelity (Li-Fi) technology has been identified as a promising candidate to meet up such demand.The first part of this work is the schematic design of the Arduino transmitter with the interfacing of Arduino receiver and the LCD for getting the real-time simulation of three different channel frequency values displayed on the LCD using the Proteus 8 professional and the latter part is the construction of the transmitter and receiver, by pressing any of the channel the visible light signal is propagated from transmitter to the receiver wirelessly to remotely switches electric lamp, standing fan and fridge on and off via visible light signal from white LED.

1.1THEORETICAL FRAMEWORK OF LIGHT FIDELITY

1.1.1Mathematical Background of Light Fidelity (Li-Fi) Transmitter and Receiver

Light emitting diodes (LEDs) are commonly used as an illuminating device due to their overall feasibility including compact size, prolong lifespan, low power consumption and minimum heat up. The same LEDs with faster response time can efficiently be used in optical wireless communication to provide high speed data links. The data rate of the transmission will depend on how fast the lights can turn on and off. LEDs are considered as a lambertian radiator which has luminance in all directions. The intensity of LED represented by $\boldsymbol{I(\phi)}$ depends upon LED colour and position of the receiver. The luminance intensity is a function of irradiance angle $\boldsymbol{\theta}$, $\boldsymbol{\phi}$ is the incident angle and the field of view ($\psi_{\boldsymbol{FOV}}$) of LED is illustrated in image 1.

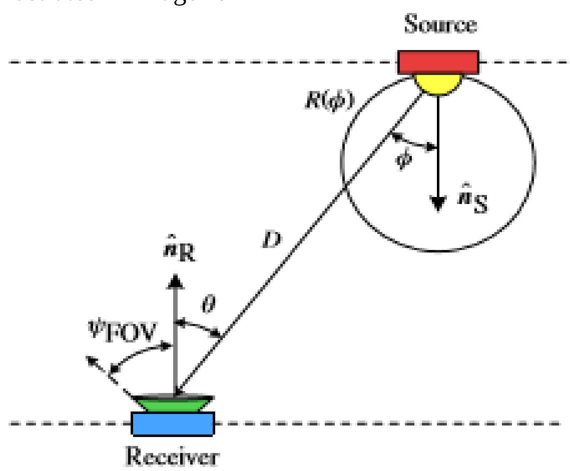

Image 1. Geometry of the Transmitter and the Receiver without Reflectors (*Hass at el*., 2015)

The transmitter is mathematically model by a position vector $\boldsymbol{r_S}$, a normalized orientation vector $\boldsymbol{n_S}$, a power value $\boldsymbol{P_S}$, and an axially symmetric radiation pattern $\boldsymbol{R(\phi)}$

a) Intensity can be calculated as (Agarwal & Saini, 2014)

$$\boldsymbol{I(\phi) = I(0)\cos(\phi)^n} \qquad (1.1)$$

$\boldsymbol{I(0)}$ is the maximum illumination, where $\boldsymbol{\phi = 0}$ and n is the Lambertian order, determining the directionality of the emitted beam. Parameter n is related to the semi-angle of half power of the light source$\boldsymbol{\phi_{1/2}}$by

$$\boldsymbol{n = \frac{-1}{\log_2[\cos\phi_{1/2}]}} \qquad (1.2)$$

b) The radiation pattern is defined as the optical power per unit solid angle emitted from the transmitter at an angle $\boldsymbol{\phi}$ with respect to $\boldsymbol{n_s}$ .It is commonly assumed that an LED transmitter has a generalized Lambertian radiation pattern (Barry *et al*. 1993)

$$\boldsymbol{R(\phi) = \frac{n+1}{2\pi} P_S \cos^n \phi} \qquad (1.3)$$

c) The luminous efficiency, also known as efficacy in the lighting community, is an important figure of merit for visible LEDs, it is defined by the ratio of output luminous flux over the consumed electrical power and is measured in lumen per Watt (lm/W). The luminous efficiency is calculated using (Kim & Schubert, 2018)

$$\eta_{LED} = \frac{683}{V_f I_f}\int_\lambda P(\lambda)V_{es}(\lambda)d\lambda \qquad (1.4)$$

where V_f is the forward bias voltage, IfI_f is the forward bias current, λ is the wavelength in the operation spectrum, p(λ) is the PSD of the LED, and V_{es} (λ) denotes the eye-sensitivity function

d) A light source S that emits a unit impulse of optical intensity at time zero is denoted by (Barry *et al*. 1993)

$$\boldsymbol{S = \{r_s, n_s, n\}} \qquad (1.5)$$

e) A receiver with position r_R, orientation vector n_R, physical area A_R, and field of view (FOV) ψ_{FOV} is denoted by (Barry *et al*. 1993)

$$\boldsymbol{R} = \{\boldsymbol{r_R}, \boldsymbol{n_R}, \boldsymbol{A_R}, \boldsymbol{\psi_{FOV}}\} \qquad (1.6)$$

f) Channel gain at the transmitter in line of sight (LOS) case is expressed in the following (Agarwal & Saini, 2014).

$$\boldsymbol{H_{LOS}} = \begin{cases} \frac{\boldsymbol{A_R}}{\boldsymbol{D}} \boldsymbol{R(\phi_i)\cos\theta_i} & \boldsymbol{0 \le \theta_i \le \theta_c} \\ \boldsymbol{0} & \boldsymbol{\theta_i > \theta_c} \end{cases} \qquad (1.7)$$

g) The channel gain at the receiver H_R includes the optical filter gain T_s and optical concentrator $g(\theta_i)$ integrated in the photodetector (Agarwal & Saini, 2014)

$$\boldsymbol{H_R} = \begin{cases} \frac{\boldsymbol{A_R(n+1)}}{\boldsymbol{D^2 2\pi}} \boldsymbol{cos^n\phi_i T_s g(\theta_i)\cos\theta_i} & \boldsymbol{0 \le \theta_i \le \theta_c} \\ \boldsymbol{0} & \boldsymbol{\theta_i > \theta_c} \end{cases} \qquad (1.8)$$

where

$\boldsymbol{T_s}$: the receiver's optical filter gain

$\boldsymbol{\theta_c}$: the receiver's FOV.

$\boldsymbol{g(\theta_i)}$: the receiver's optical concentrator gain

$\boldsymbol{\phi_i}$and $\boldsymbol{\theta_i}$ are the angles of radiance with respect to the transmitter plane and the receiver plan respectively.

h) The optical concentrator gain of the receiver is given by

$$\boldsymbol{g(\theta_i)} = \begin{cases} \frac{\boldsymbol{m^2}}{\boldsymbol{\sin(\theta_c)^2}} & \boldsymbol{0 \le \theta_i \le \theta_c} \\ \boldsymbol{0} & \boldsymbol{\theta_i > \theta_c} \end{cases} \qquad (1.9)$$

where m is the refractive index.

2.0 BLOCK DIAGRAM DESCRIPTION

This method involved the use of fast light pulses to transmit information via wireless technology refers to as Li-Fi.The block diagram of the proposed system is shown in figure 1.

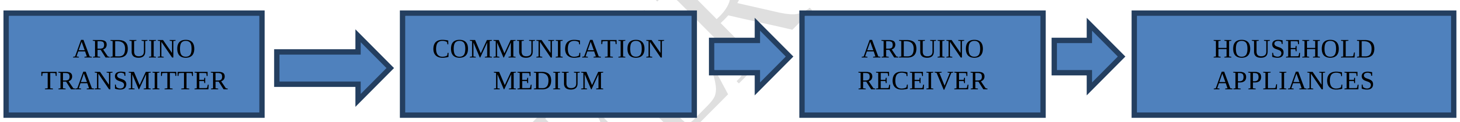

Figure 1: System's Modules

Arduino receiver is programmed such that the connected household appliances are controlled based on the signal sent by the Arduino transmitter through the wireless communication medium.

2.1 Arduino Transmitter

Arduino Transmitter consists of the 9v battery, white LED and three (3) functional push buttons respectively. The whole transmitter section circuitry is powered by 9v battery through the Arduino transmitter 5V pin. When the functional pushbutton of any of the three (3) channels on the transmitter is pressed, the corresponding signal is sent which is received by the 5V YF 75x28 solar panel. The mode of operation can be better understood given the transmitter schematic diagram shown in Figure 2.

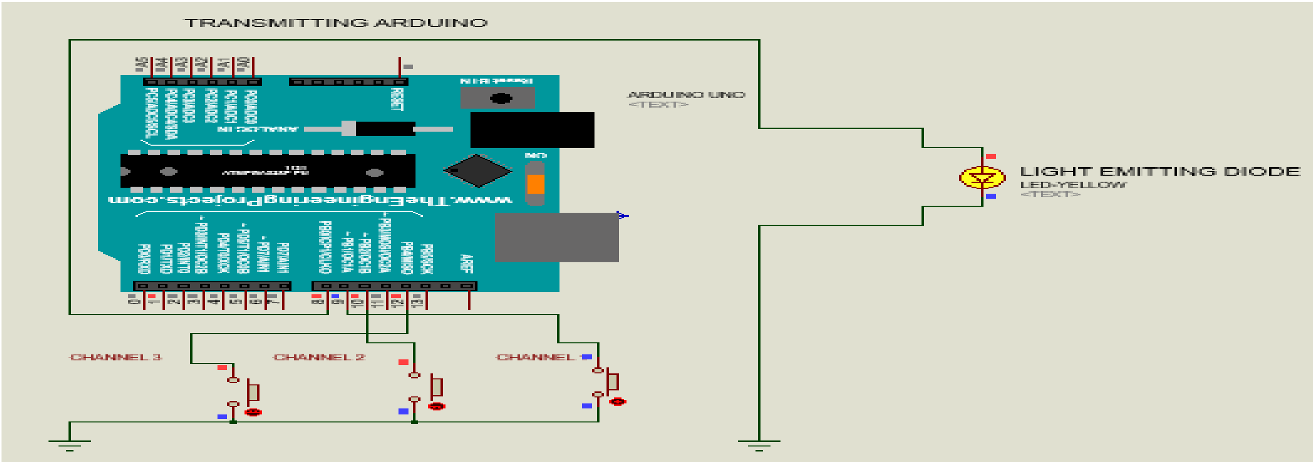

Figure 2: Arduino Transmitter Schematic Diagram

When one of the functional pushbutton is pressed or held down, the circuit of the transmitter is completed and the transmitting arduino microcontroller receives the input signal from the pushbutton and the digital output pin 8 of the transmitting arduino turns on the LED, the LED sends its visible light signal oscillating at a frequency corresponding to the channel.

2.2Communication Medium

Light fidelity is the technology used in this project where visible light pulses emitted from the white LED as the source of the communication signal and air as the medium is used to connect Arduino transmitter to the core of the system. These help users to control household appliances within certain distance from them.

2.3Arduino Receiver

The Arduino receiver has two major section that operate together to receive the visible light signals and generate the electrical signal according to received signals to carry out the switching operation. Three (3) channel 6V switch relay have been used for switching the household devices ON/OFF. Schematic diagram of the receiver is shown in figure 3.

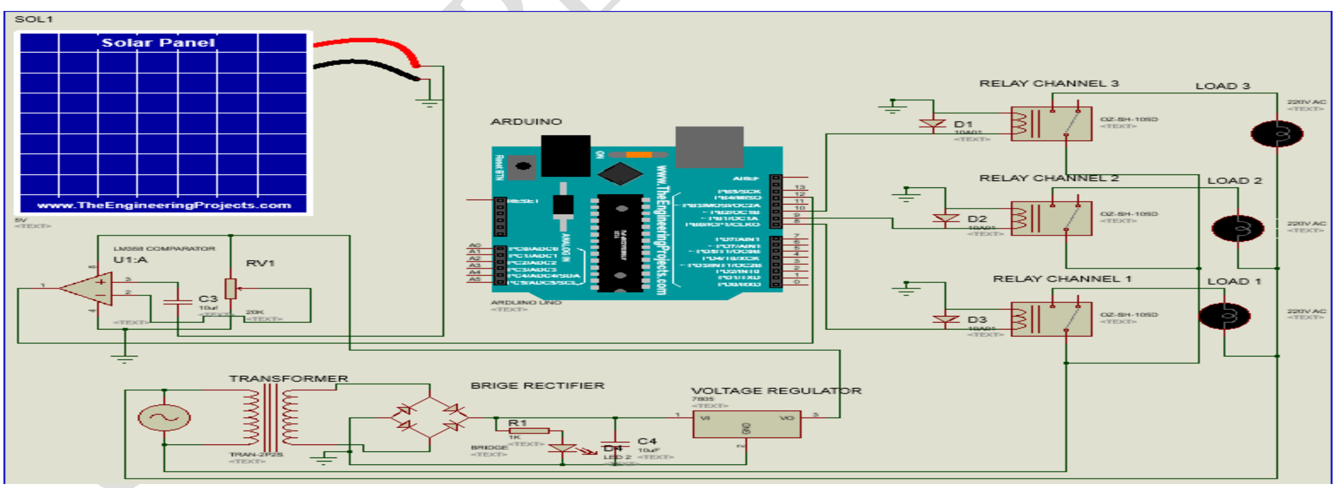

Figure 3: Schematic Diagram of the Receiver

a) **<u>Power Supply</u>:** The power supply comprises of the following components 220/240V, 50Hz transformer, bridge rectifier, voltage regulator (L7805) and 10µF, 25V filter capacitor. It involves rectification of AC to DC and the DC power supply provides the voltage required to the Arduino for proper operation. The transformer steps down the AC voltage to 12 V, the bridge rectifier carries out a full wave diode rectification to give an output voltage. The output voltage is regulated by the voltage regulator (L7805) to give a 5V. This 5V power the operational comparator (LM358P) circuit, relay and the arduino.

b) **<u>The Controlling Section</u>:** This section of the system is a control circuit responsible for receiving the visible light signal from the Arduino transmitter, processed the signal and controls this visible light signal to their respective loads or outputs. It comprises of the following component: 5V YF 75x28 solar panel, LM358P operational amplifier, capacitor, three diodes, 10kΩ potentiometer, Arduino and three 6V switch relays etc.

5V YF 75x28 solar panel detect and receives the variation in the visible light signals of the LED from the transmitter at a frequency generated by Arduino transmitter depending on the channel and convert it into equivalent voltage signal, this signal passes through the LM358P configured as a comparator with 10kΩ potentiometer and 10µF to filter and get the control as well as the amplification of the received signal in its electrical form and this signal is sends to the digital input pin 12 of the Arduino receiver. Arduino is used as an interface between 5V YF 75x28 solar panel and household appliances. The Arduino receiver senses the received input signal from YF 75x28 solar panel. The output of the Arduino receiver from pin 8, 9 and 10 each is fed into one of the input coil of the three relays respectively. The common terminals of the three relays are connected to the AC source terminal and to the control terminal of the load. The normally open terminals of the three relays are connected to the switching terminals which are used to achieve remote control. The second terminal of the load is then connected to the control terminal of the relay. When the relay is switched to one path, the connected load is turned ON, when the relay is switched to different path, the load is turned OFF.

2.4Household Appliance

The receiving Arduino issues command to the household appliances and the device connected will switch ON and OFF which are electrically controllable. Electric lamp, standing electric fan and fridge are the three basic household device used in the experimental testing of the proposed system to ensured proper working of the system.

3.0 OPERATIONAL FLOW OF THE SYSTEM

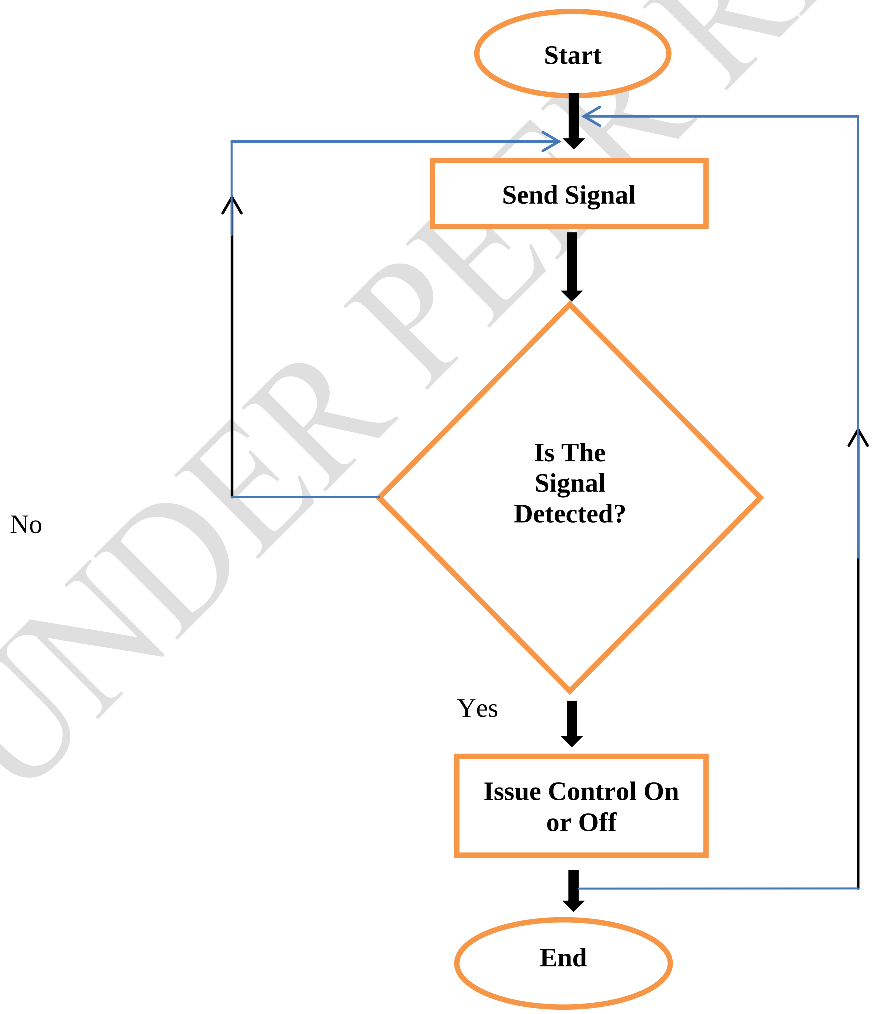

Figure 4: System’s flowchart

3.1 IMPLEMENTATION OF THE TRANSMITTER AND RECEIVER CIRCUIT ON A TEST BOARD

Implementation of the Arduino transmitter and Arduino receiver circuit on a test board is for clarification purposes and testing of components functionality and reliability. The project design was carried out on a test board to ensure proper connection for testing as shown in plate 1 and 2.

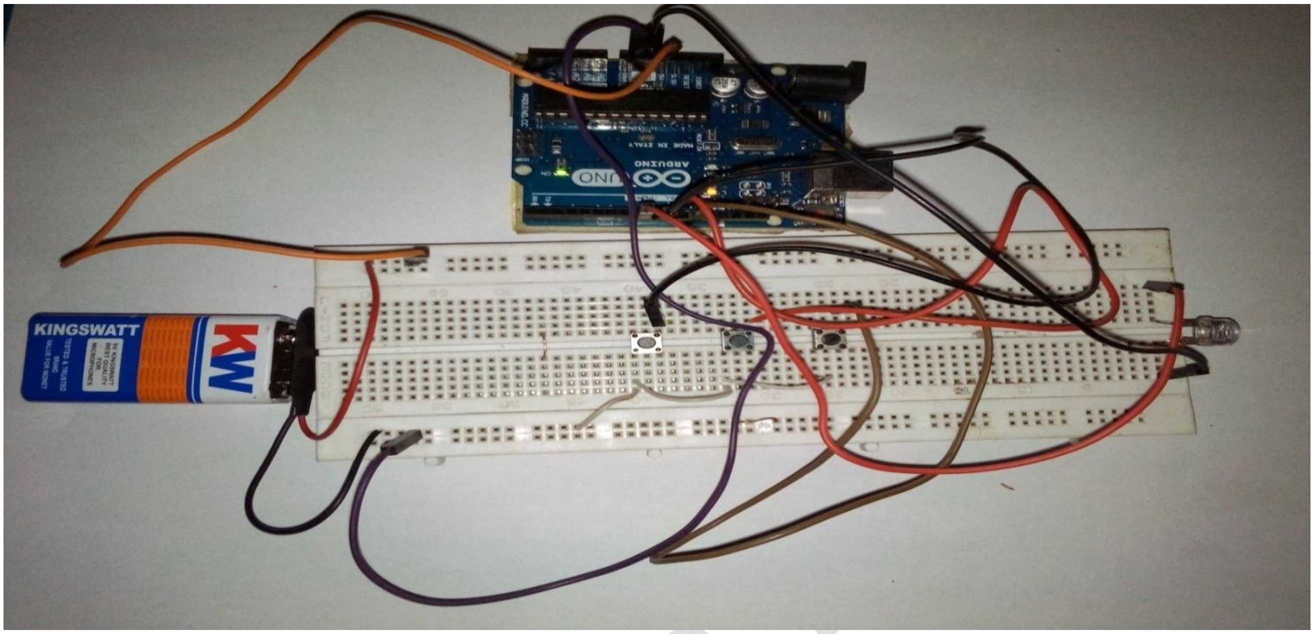

Plate 1: Implemented Arduino Transmitter Circuit on the Test Board

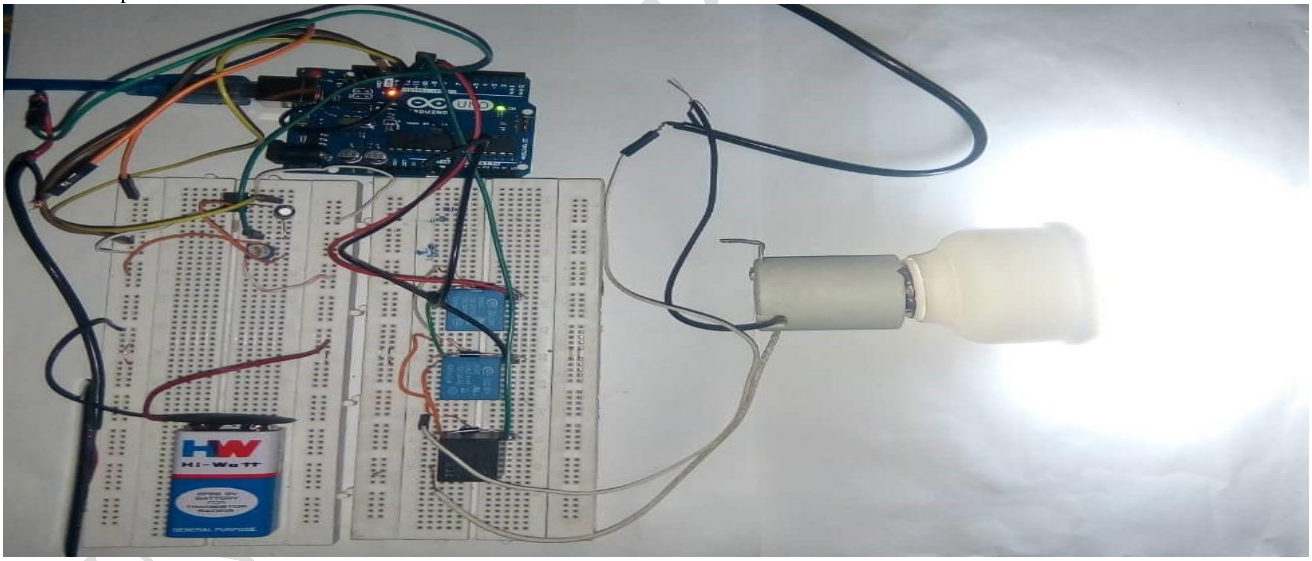

Plate 2: Implemented Arduino Receiver Circuit on the Test Board

The functionality of the system depends to some extends on the correctness of the exact visible light signals being produced by different channels from the Arduino transmitter, on the test board, visible light signals sent through the Arduino transmitter by pressing channel pushbuttons on the board were transmitted at predefined frequency to the receiver and the action of the signal received caused the switching ON and OFF of the household appliances connected at the output section of the receiver. The result from test-running the circuit on the test board to ON electric lamp was positive as shown in plate 2.

3.2 CONSTRUCTION OF TRANSMITTER AND RECEIVER ON A VERO BOARD

Prior to the positive result obtained from a test board, construction and implementation of the circuit on a vero circuit board was carried out. The components were arranged on the vero circuit board following the specification of the circuit design. The constructions of the work on the vero circuit board are as shown in Plates 3 and 4.

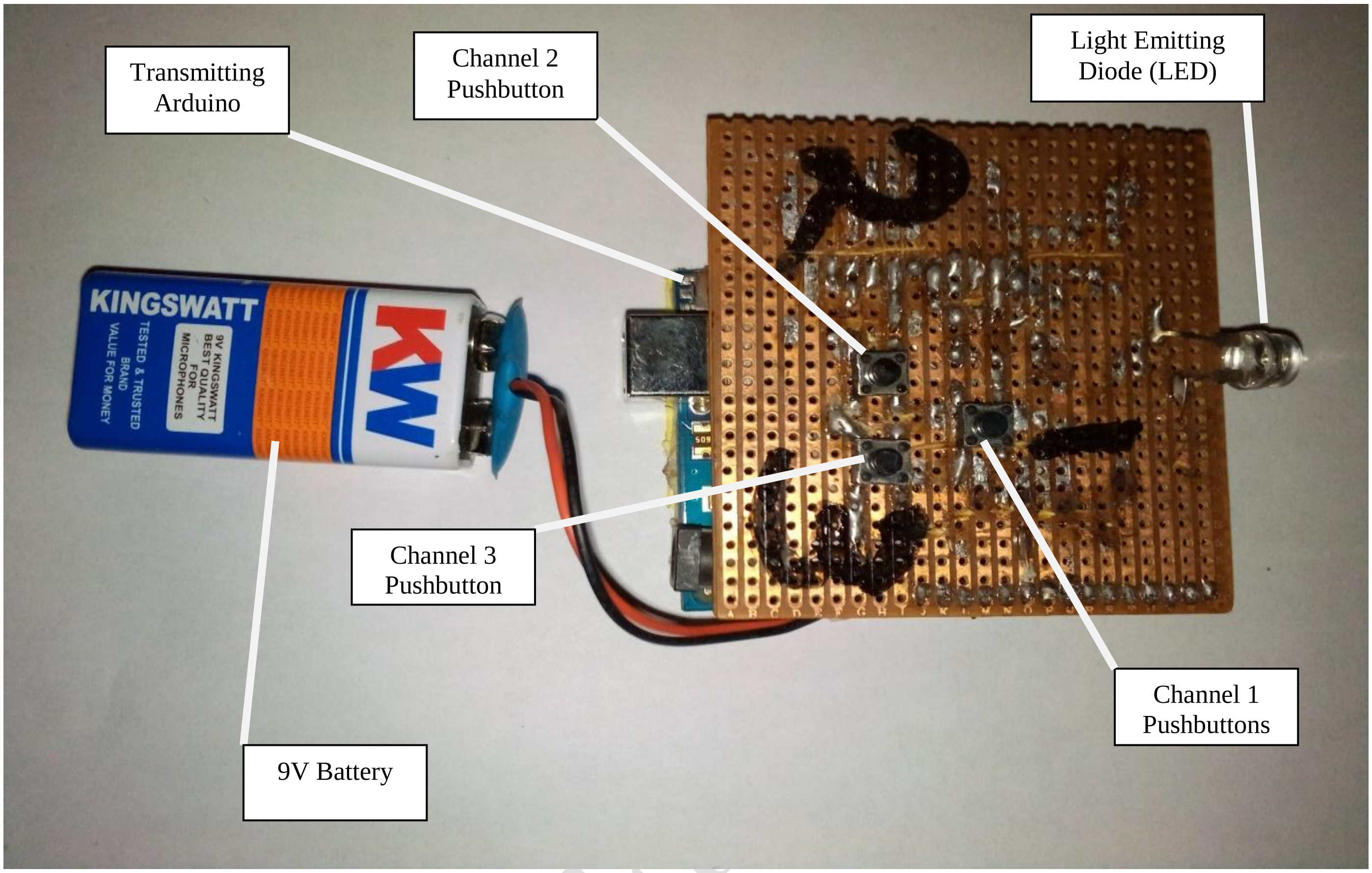

Plate 3: Implemented Arduino Transmitter Section.

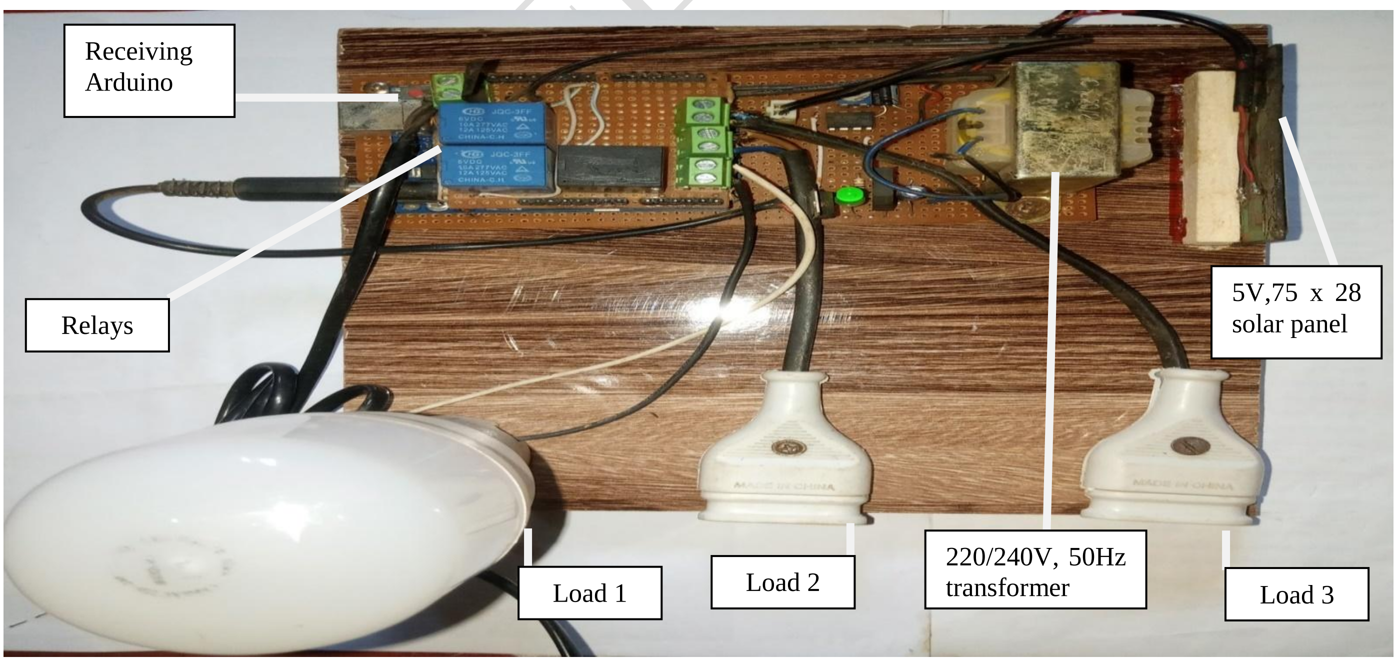

Plate 4: Implemented Arduino Receiver Section

4.0RESULTS AND DISCUSSIONS

The performance of the proposed system was tested through simulation of the design using ISIS-Proteus software and then the hardware implementation was carried out and the prototype was put into operation by switching on and off household appliances. The system performed as expected.

4.1TRANSMITTER STAGE

The Arduino transmitter successfully performed the expected task of sending a light signals based on the electrical inputs and outputs of the white LED bulb controlled through the transmitting Arduino. The frequency of the signals generated by the Arduino transmitter is of minimum duty cycle of 50% (i.e square wave); these light signals were modulated by transmitting arduino to the receiver. Figure 2 shows the Arduino transmitter schematic design, plate 1 and plate 3 shows the test board and the vero board practical implementation of the Arduino transmitter. The household appliances were successfully switched on and off as shown in plate 2. Integration of arduino Li-Fi based remote control device was due it is excellent frequency generation and stability. The designed remote control device was user friendly and cost effective.

4.2 RECEIVER STAGE

The receiver in figure 3 has two major sections: The controlling section consists of 5V YF 75 x 28 solar panel that detect and received light signal from either channel1,channel2 or channel3 at a predefined frequency of 480Hz, 288Hz or 207Hz. The power section supplied power from 220/240V, 50Hz step down transformer rectified and regulated to 5V dc by the L7805. The 5V regulated dc supplied power to the receiving arduino, relays and the LM358P comparator. These signals was filtered and amplified by LM358P comparator with 10kΩ potentiometer and 10µF to deal with the distortion in the signals and then sends to input pin 12 of receiving arduino. The receiving arduino has been kept in line of sight with the transmitting arduino; any change in position of either transmitting or receiving arduino out of line of sight during transmission can result in loss of signal. The receiving arduino microcontroller has been used to sense and processed the rising and falling of the voltage and recorded the rising time and falling time as a period which is then converted to frequency. These frequencies once match the predefined frequencies of the channels assigned for each household appliances then the channel will be activated and switches the connected household appliances on and off. The two electric lamps in figure 3 were replaced with standing fan and fridge, respectively.

4.3 TRANSMITTER & RECEIVER

The transmitting arduino pins 9, 10, 12 and receiving arduino pins 8, 9 and 10 are programmatically designed to control the light signal which is used to control the switching relay operations as analyzed in table 1.

Table 1: Analysis of Signal Transmission

Transmitter			Receiver		
Button	Arduino Transmitting Input Pin	Channel frequency (Hz)	Tolerance (Hz)	Arduino Receiving Output Pin	Load triggered
CH1	9	480	$480 \le f < 485$	8	Electric lamp
CH2	10	288	$288 \le f < 293$	9	Standing fan
CH3	12	207	$207 \le f < 212$	10	Fridge

Inclusion of the tolerance of 5Hz for all the three (3) channels in the receiving arduino IDE shown in table 1 was to compensate the slight increase in the predefined frequency of the transmitted signal shown in figure 5, the intermediate LM358P comparator with 10kΩ potentiometer and 10µF capacitor in Figure 3, these components amplifies or reduces the input voltage to a selected output voltage to make sure the signal is digital and stable before the receiving arduino. Each of the connected household appliances triggered only in the tolerance range. The completed project has been developed for switching three household appliances: a lamp, standing fan and fridge and other household appliance that can be switched on and off successfully.

4.4 PROTEUS SIMULATION RESULT OF THE PROJECT

Figure 5 shows the computer aided simulation of the project for both the transmitter and receiver which was carried out using standard computer software proteus 8 professional. In this the receiving arduino circuit which contains the microcontroller is getting the input voltage directly from the digital output pin 8 of the transmitting arduino when any of the functional pushbutton is pressed. A program was written on both the transmitting and receiving arduino to send and accept this input voltage through the digital input pin 12 of the receiving arduino board and to display the channel value frequency of the corresponding voltage on the 16 x 2 LCD.

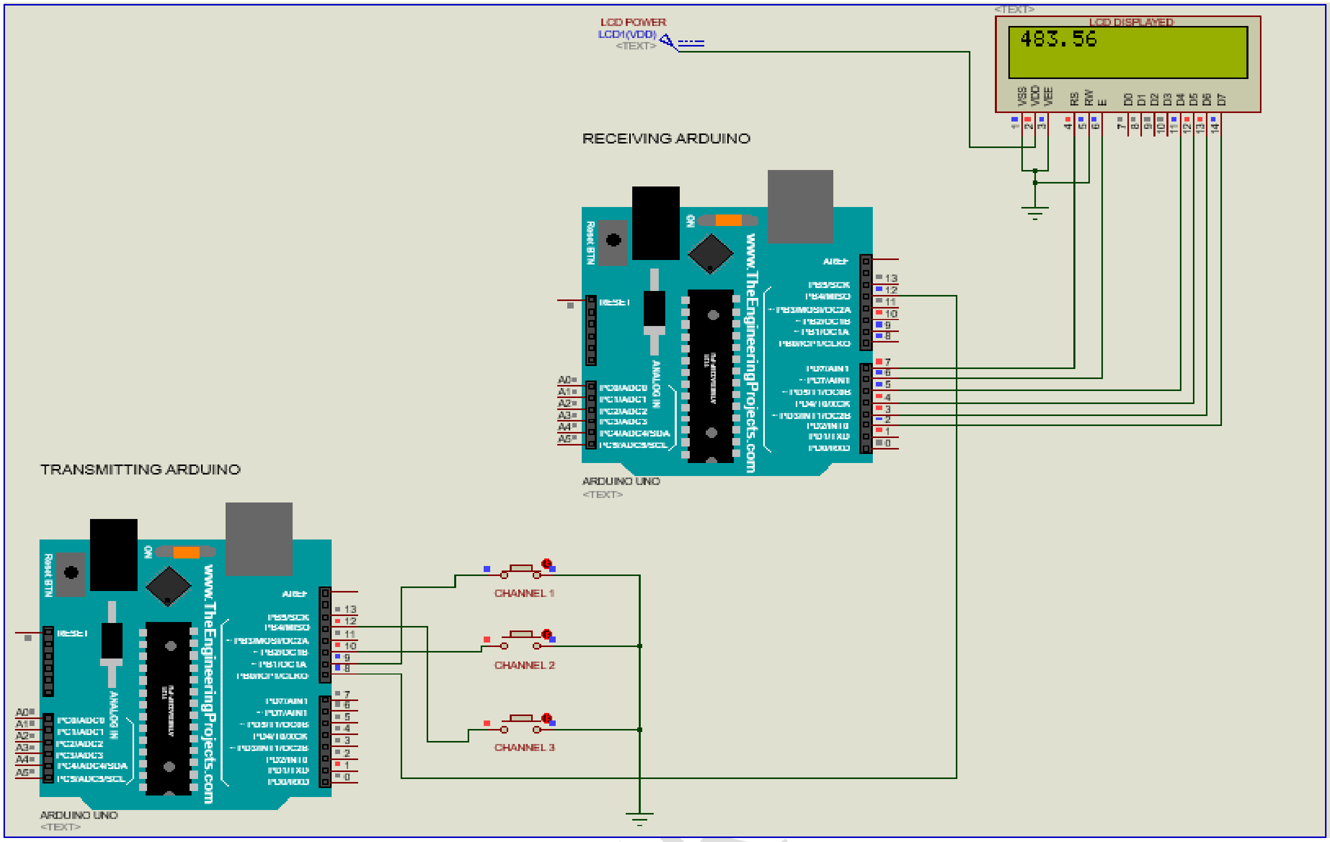

Figure 5: Proteus Real-time Simulation of Transmitter and Receiver.

To achieve a practical communication to the receiver through visible light signal, digital output pin 8 of the transmitting arduino was connected to the white LED to convert the voltages into equivalent visible light signals which when captured on the receiver will result in converting the corresponding visible light signals to voltage signals that will trigger the household appliances connected to output pin 8, 9 and 10 of the receiving arduino.

4.5 TESTING

Tests were conducted to verify the design and see if the right properties were achieved for the performance of both the transmitter and receiver section of the project shown in plate 1 and plate 2 while the project was implemented on the vero circuit board as shown in plate 3 and 4 respectively. The power supply was tested to ensure that it gives the expected voltage of 5V and it tested positive. After construction of the designed transmitter and receiver, the final experimental verification and demonstration was confirmed by the successful control of the electric lamp, standing fan and fridge on and off, respectively using the arduino Li-Fi based remote control device. It was observed that the transmitter and receiver can communicate upto a maximum distance of 41cm.

5.0 CONCLUSION

The Arduino transmitter and receiver envisaged in this study with light fidelity technology can only transmit and receive data/signal within a line of sight. It is shown that the transmitter and receiver achieved transmission and communication within the maximum distance of 41cm and the whole system has been demonstrated to be functioning, user friendly and cost effective. The system control home appliances ranging from the electric lamps, the standing fan to the fridge etc. The nature of this project is such that it provide a great scope for further development and some security measures can be incorporated to avoid interference of the neighboring light signals, effort in such direction will help realized a truly wireless and a fully automated home automation system. Light fidelity technology can even work underwater where Wi-Fi fails completely and in places where Bluetooth, infrared, Wi-Fi are banned.

5.1 RECOMMENDATIONS

The following is a suggestion to improve on future designs, since the system covers only a distance of 41cm, high capacity LEDscan be used or a modulation technique can be incorporated so as to increase the distance beyond 41cm.

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