Data transmission using Li-Fi technology incorporating an intruder detection and alerting system

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Abstract

In this project, a simple intruder detection and alerting system using Li-Fi technology is discussed. The motive was to show the benefits of using light for data transmission from indoor IoT devices to their IoT gateway. The system can not only transfer real-time data continuously, but also incorporate an intruder detection scheme which is possible due to the intrinsic security nature of light. This project also compares the transmission distance achievable using different light sources such as LED and Laster.

Index Terms

Light Fidelity, LED, Laser Diode, LDR, Intruder Detection.

I. Introduction

We are living in a world of uncountable number of connected smart devices which interact and produce huge amount of real-time data. According to [1] there will be around 30.9 billion active connections over IoT in 2025. An unavoidable application of IoT is the automation of homes, usually termed as Smart Home. Smart IoT devices equipped with powerful sensors can detect, identify and provide mitigation services to users in a real-time fashion. These devices can adjust the temperature or humidity of the room and alert the user, switch on and off lights depending on user movement, play music that satisfy the user, open or close house doors and windows based on whether the user is inside or outside. Although, these smart devices can ease our day today life, they also incur many security challenges. Analyzing and updating these device chips as well as protecting data communication through connected network system is crucial. If not properly managed, a hacker can access these devices through the connected Wi-Fi. On the other hand these devices produce massive amount of data at real-time which are uploaded to the cloud for analysis [2].

One of a useful use cases of IoT is the intruder detection system. Such systems are usually deployed in restricted locations or private areas such as home or office. An intruder can enter such locations and can damage property or steal valuable items. It is convenient to establish an intruder detection system, using advanced IoT products, which can save once life from unexpected moments. Many intruder detection systems has been developed but all of them requires specialized equipments for detection and alerting [3].

With the introduction of Li-Fi technology, wireless data transmission has reached a new milestone. Because of its intrinsic security nature due to non-penetration through solid objects, it can be used for secure local area communications. Li-Fi is characterized by huge underutilized portion of electromagnetic spectrum. Due to having high bandwidth, this technology can be used for multiple indoor communication purposes. Availability of high speed LEDs and Laser diodes has proven to provide data rates up to 10 GB/s [4]. Considering all of these aspects of Li-Fi technology, it is quite compelling to use this technology for data transmission between smart devices with their receivers which can incorporate the obstacle (intruder) detection scheme.

A. Motivation

The main objective of this project is to realize Li-Fi technology in practical applications such as device to device communication incorporating an inbuilt intruder detection scheme. Due to high transmission rate and low interference with other radio waves, light can be used as a medium for future data transmission. With this project the aim is to show, under proper conditions, light is most suitable for data transmission for indoor applications.

II. Li-Fi Technology

Li-Fi or Light-Fidelity is a new technology that aims at transmitting data wirelessly through light. The term was first introduced by German physicist Harald Haas in 2011, who is a professor at University of Edinburgh and founder of pureLiFi. He is acknowledged as the founder of Li-Fi. During the TED Global conference in Edinburgh in 2011, he demonstrated data transfer through a table lamp powered by LED [5]. He showed that the lamps with LED light sources can act as transceivers that can transmit data at high speed compared to existing Wi-Fi technology [6]. This facilitates that the existing light sources can not only be used for lighting a room but also for fast data transfer. On the other hand, Li-Fi has advantages over Wi-Fi that, Wi-Fi only uses radio-frequencies ranging from 2.4 GHz to 5 GHz for internet connections and has a bandwidth limitation

TABLE I: Li-Fi to Wi-Fi comparison

	Li-Fi	**Wi-Fi**
Spectrum	10,000 times wider than Wi-Fi	Narrow
Bandwidth	High	Low
Speed	Up to few Gbps	In the order of Mbps
Security	High, since non-penetration and non-bending nature of light	Low due to bypassing obstacles
Reliability	Medium	Medium
Data Density	High	Low
Interference with Obstacles	High	Low
Latency	Millisecond range	Microsecond range

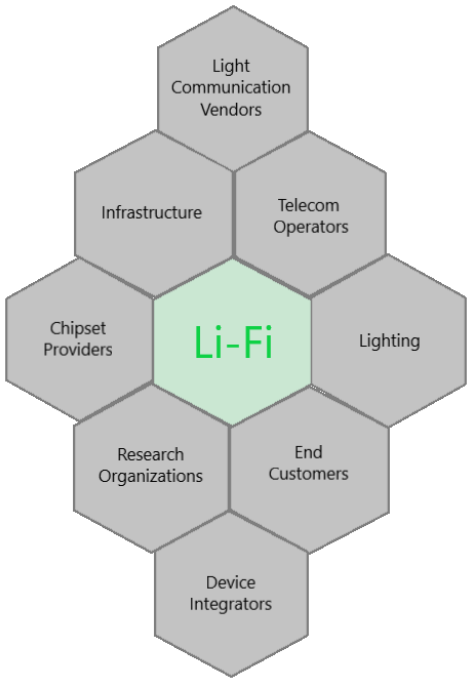

Fig. 1: Li-Fi Ecosystem

of 50 Mbps to 100 Mbps. With increasing use cases, this will become a bottleneck for future volume of Wi-Fi traffic. On the other hand, Li-Fi has huge underutilized portion of electromagnetic spectrum. There are also other concerns such as security and speed, which also makes Wi-Fi less feasible for certain scenarios. Table I shows a comparison of Li-Fi over Wi-Fi.

Apart from the high speed and broad spectrum that Li-Fi technology provides, there are quite a lot of advantages of using Li-Fi, as listed below:

- Li-Fi uses *Free bands* which does not require licensing.
- High availability of light sources makes Li-Fi technology faster to establish.
- LED or Laser diodes require less energy than other light sources.
- Free from electromagnetic interferences due to other radio-frequency signals.
- High speed On-Off rates of LED and Laser diodes leads to fast transfer.
- Toxic free light sources (LED and Laser diodes) compared to fluorescent bulbs.
- limited radio-frequency bandwidth is tackled by Li-Fi (Spectrum Relief).

Li-Fi technology is getting more and more support from the industry. Multiple vendors, research organizations and chipset provides have showed more interest towards Li-Fi. Figure 1 represents an illustration of Li-Fi ecosystem [11].

A. Li-Fi Operation

Li-Fi comes under Visible Light Communication (VLC) where, the data transmission is carried out by generating rapid pulses of light. As mentioned above, Li-Fi has a potential to compete with Wi-Fi and so gained its name. In principle, an LED or Laser diode can produce light pulses with a latency of less than 1 μs. Due to their low latency, they can be switched on and off to produce binary data. When the LED is switched on, it is represented as bit 1, when it is switched off binary value 0 is realized. As the rate of On-Off is very high, human eyes won't recognize it as flickering. Thus switching on and off of the LED depending on the input electrical signal leads to production of continues stream of binary data corresponding to the input data.

An important component of Li-Fi based transmission is the light sensitive receiver. It can be either a LDR (light-dependent resistor or photo-resistor) or a photo-transistor. These photo detectors are capable of detecting variations in light and produce corresponding voltages. This will produce electrical signals corresponding to the data from the transmitter. Using high speed LEDs or Laser diodes, a transmission rate of above 100 Mbps can be achieved easily. This also means that the photo detector needs to be very sensitive to capture even a high rate of change of light intensity. Even though the data transmission requires fluctuating visible light, the intensity of the light can be reduced to a level where it won't be recognizable to human eyes, but still transmitting the data.

There are already a lot of practical use cases and products available in the market using Li-Fi. In 2014, PureLiFi introduced Li-1st as the first available Li-Fi system [7]. In the same year, Stins Coman, a Russian company, developed a Li-Fi based local network know as BeamCaster. They claimed a data transfer rate of 1.25 GBps [8]. Frank Deicke from Fraunhofer Institute, Dresden, Germany, who steer the Li-Fi development in the department of Photonic Microsystems has said that the Li-Fi can realize data rates similar to USB which is quite difficult with Wi-Fi. In 2018, BMW tested Li-Fi in their industrial environment and confirmed passing the tests [9]. In 2019, Oledcomm, a French company, did a successful test of Li-Fi at the Paris Air Show. They are collaborating with Air France to test Li-Fi on aircrafts [10].

B. Li-Fi Modulation Techniques

The IEEE 802 workgroup has standardized the VLC communication protocol. The 802.15.7 standard defines the media access control (MAC) layer and physical layer (PHY). The MAC layer comprises of 3 access techniques such as broadcast mode, peer-to-peer and star configuration. The physical layer consists of 3 types: PHY 1, PHY 2 and PHY 3, and incorporate different modulation techniques.

The data transmission through LEDs or Laser diodes are modulated using different schemes. The modulation is performed on the carrier signal, which are light pulses. Following list gives some of the modulation schemes used in Li-Fi systems:

- On-Off Keying (OOK) : It is accomplished using Manchester coding, so that the positive pulse and negative pulse have the same period. The disadvantage is the requirement of double bandwidth for transmission.
- Colour Shift Keying (CSK):It uses RGB-type LEDs. The colour combination produced by combining RGB lights are used to carry data. Due to using colours to encode data, the output light can have near constant intensity.
- Frequency Shift Keying (FSK): Same as used in radio-signal transmission technologies, carrier signal is modulated with two different frequencies to represent 1 and 0.
- Variable Pulse Position Modulation (VPPM): Here the pulse position within a provided time period determine the data. VPPM permits pulse width to be adjusted to support dimming light, as compared to PPM.

C. Li-Fi General Applications

Due to high security, speed and low interference with radio-signals, Li-Fi technology has may practical applications as follows:

1) Home Automation: Due to high speed compared to Wi-Fi, Li-Fi technology is seen as suitable for home automation where large real-time data transfer may be required due to IoT. Such bulk data transfer in indoor situations are most supported by Li-Fi. Due to closed room environment, it also provides secure connection as outsiders won't be able to access the network from other side of the wall. This also prevents cyber attacks against IoT devices [11].

2) Industrial Automation: Industry environments are characterized by transmission of high speed data in huge amount real-time. In such a situation, Li-Fi can be used as a replacement of short cables such as Ethernet, due to its high speed [12].

3) Medical and Healthcare: Hospitals are usually equipped with medical and monitoring instruments. Using Wi-Fi in hospitals may result in interfering with these instruments such as MRI scanner. Also, due to radiation reasons many hospitals does not allow Wi-Fi equipped computers and cell phones. In such situation Li-Fi is more beneficial as it does not cause interference. Also, light is significant part of medical testing and operating rooms [13].

4) Aviation: Due to interference reasons, Wi-Fi is prohibited in aircrafts. Since aircrafts are equipped with visible lights, they can make use of Li-Fi [13].

5) Vehicles: Since vehicles already contains front and rear lamps, they can use them to prevent accidents. Using traffic lamps, signals and street lights constructed with LED, they can be use for vehicle-to-vehicle communication [14].

6) Advertising: Street light or lights near a shop can display advertisements related to new offers and discounts. People who are walking through this place can then see these advertisements and can decide on purchase [15].

7) Underwater Explorations: Remotely Operated Underwater Vehicles (ROV) are connected and coontrolled by wired cables. The length and weight of the wire can limit the exploration area. On the other hand, Li-Fi based communication is easy and more flexible [16].

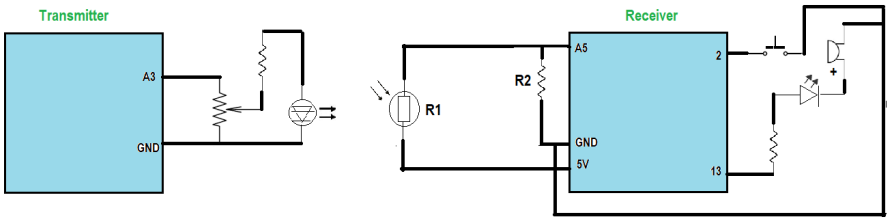

Fig. 2: Schematic digram

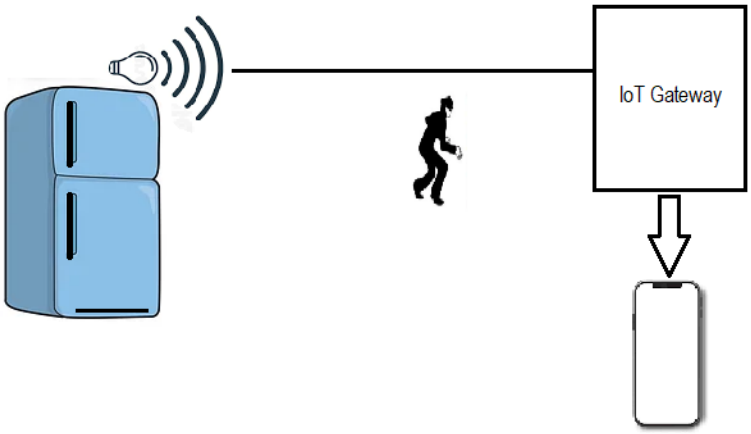

Fig. 3: Home appliance using Li-Fi technology with detection mechanism

III. Architecture

The presented Li-Fi data transmission system consists of a transmitter module and a receiver module as shown in Figure 2. The transmitter module can be incorporated as part of a home appliance. The real-time data produced by the appliance can be collected by the transmitter module and send it using Li-Fi technology. The transmitter module consists of a controller that produces binary data in the form of electrical pulses. The generated electrical pulses then can be fed to a high speed LED or Laser diode to produce light pulses. The system uses OOK modulation along with synchronized clock for data transmission.

The receiver module can be equipped inside an IoT gateway. The receiver module consists of a light detector that receives transmitted data. Some of the light detectors available are: light-dependent resistor (LDR) and photo-transistor. For the purpose of this project, LDR has been used as the light detector. The LDR is a passive component. The resistance of a LDR varies with respect to the intensity of the light hit on its sensitive surface. The resistance gets decreased when more light is hit on the sensitive surface. From the Figure 2, the voltage generated at the output pin $A5$ can be calculated using Equation 1:

$$V_{out} = \frac{R2 \times 5V}{R1 + R2} \tag{1}$$

For a transmitted data, corresponding fluctuating voltage is generated at the receiver module. This electrical pulses can be then be fed to a controller to regenerate the original transmitted data.

Since the system is suitable for real-time data transmission without interruption, an obstacle placed between the path of transmitter and receiver can cause low voltage generated at the receiver LDR. This indicates that the communication is being obstructed. If the receiver is blocked for more than a threshold period of time, indicates the presence of an intruder. The receiver side controller can then identify this situation and generate an alert. Figure 3 represents application of Li-Fi technology in home appliance communication system incorporating intruder detection mechanism.

IV. System Implementation

A. Hardware Used

- Transmitter

  - Arduino Uno
  - Laser Diode
  - Potentiometer
  - Resistor
- Receiver
  - Arduino Uno
  - LDR
  - Resistors
  - Reset Button
  - Buzzer
  - LED

B. Hardware Setup

Figure 4 illustrate the hardware setup for the Li-Fi transmitter receiver system. The transmitter side has a Arduino Uno Microcontroller which transmit the electrical pulses corresponding to the data to a Laser diode. The voltage of the transmitted data can be adjusted using a Potentiometer. A 220 ohm resistor is used to reduce the current through the circuit so that the Laser won't get damaged. The Laser diode then transmit these electrical pulses as light pulses in an on and off mode.

The receiver side also consists of a Arduino Uno Microcontroller that connects to a LDR as explained in the architecture section. The LDR receives the light pulses transmitted from the transmitter side. Depending on the intensity of the received light, the LDR creates voltage fluctuations which is received as electrical pulses. Since the receiver also contains an alerting mechanism, it make use of a Buzzer and a LED to notify detection of an intruder. A Button can then be used to reset the alert system once it is being resolved.

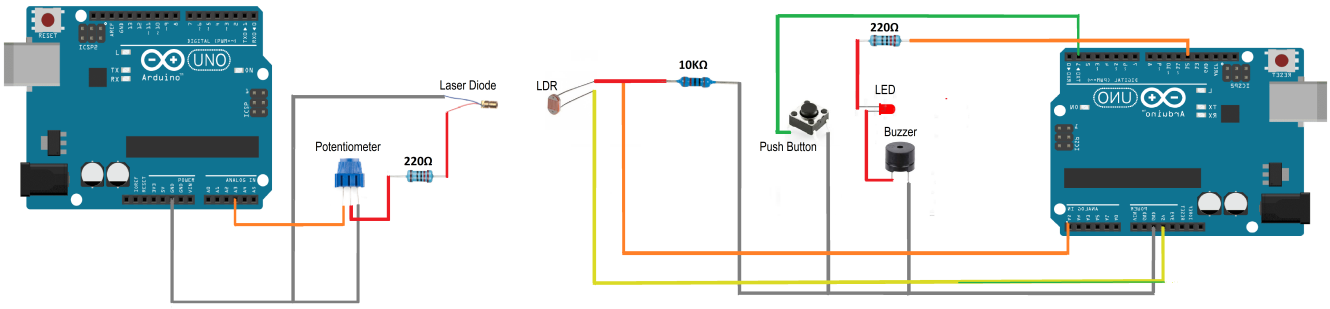

Fig. 4: Hardware Interface

C. Actual Connection Setup

Images of actual implementation are shown in Figure 5 and 6:

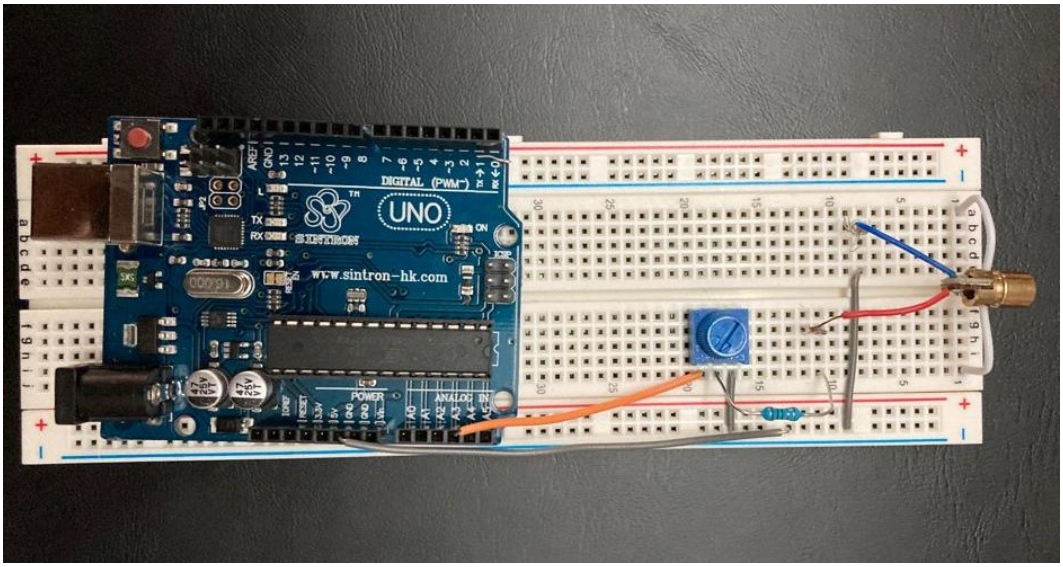

Fig. 5: Transmitter Setup

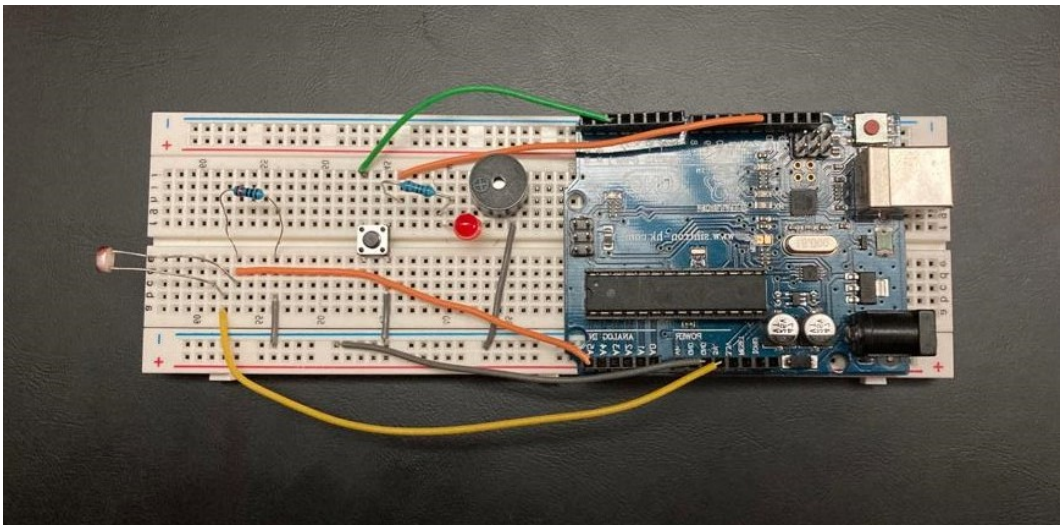

Fig. 6: Receiver Setup

D. Software

In order to develop firmware application for the project, Arduino IDE is used. Transmitter and receiver programs are provided in Appendix. Even though the transmitter is a simple data transmission program, the receiver application require attention. Figure 7 represents a flowchart of the receiver application.

V. Result

Data transmission between transmission module and receiver module is monitored using Arduino IDE's Serial Monitor. Figure 8 is an example monitored output showing normal data transfer along with intruder detection alerts.

Table II shows the transmission distance achieved for LED and Laser diode with and without surrounding light. The LDR used is: 5 mm GM5539, with light resistance of 10 Lux; the LED used is: 3v 5mm white type, and the Laser diode used is: 5mW 5V with 650nm wavelength. Without surrounding light (dark surrounding) indicates LDR voltage generated in Equation 1 is less than 10 millivolt, when no data transmission is happening. With surrounding light (bright surrounding), LDR voltage generated is 300 millivolt.

VI. Future Scope

A. Better Photo Detector

For realizing fast data transmission, the photo detector needs to be more quicker to light intensity changes. The LDR is less reactive to changes in light and so is slower in detecting light pulses. As a result, the data transmission rate obtained is limited.

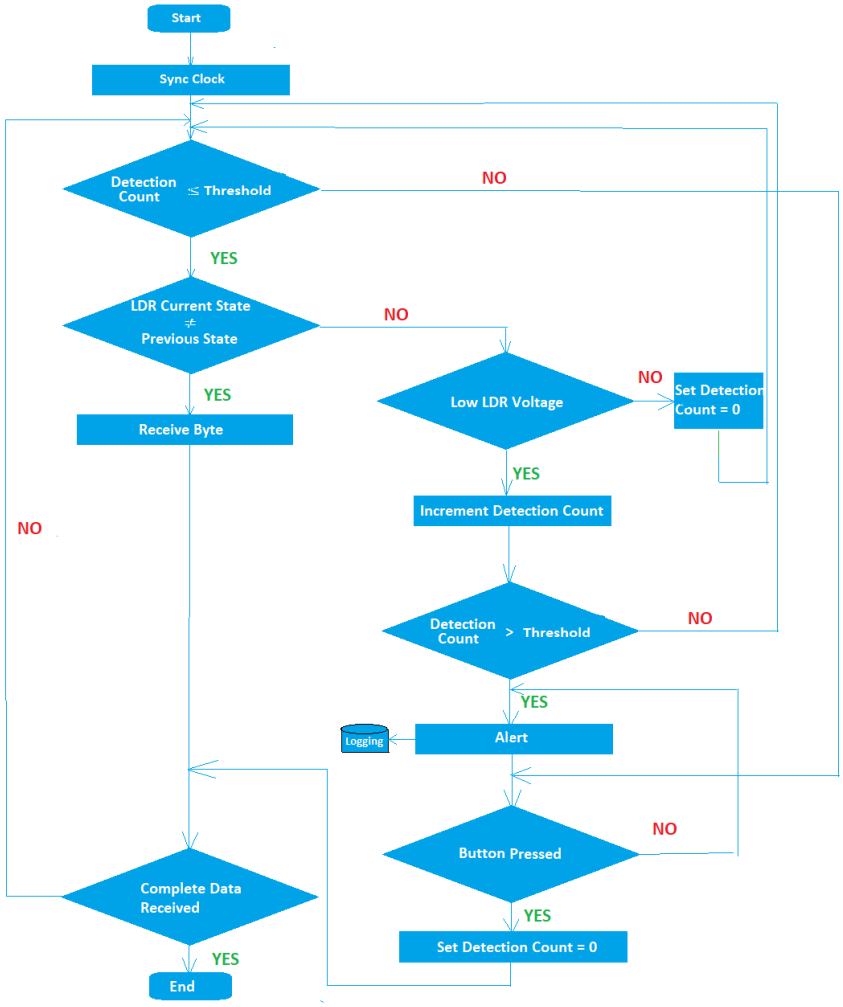

Fig. 7: Software Flowchart

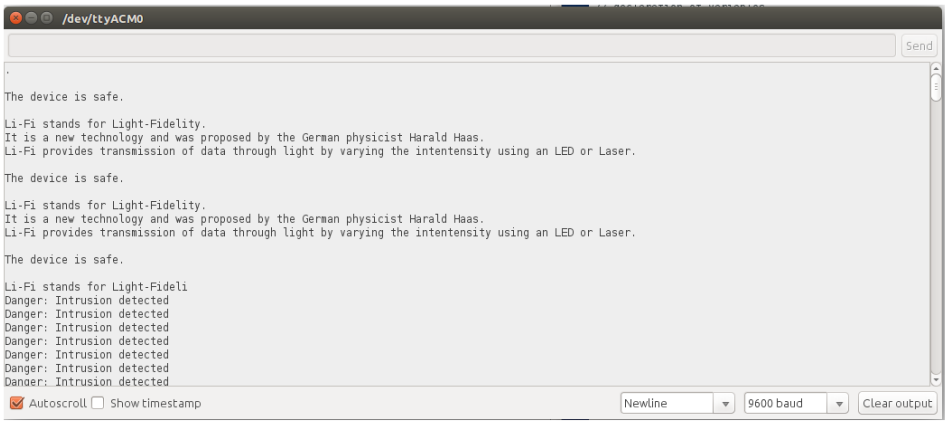

Fig. 8: Output Monitor

TABLE II: LED to Laser Diode comparison

	LED	**Laser Diode**
With surrounding light	1 cm - 2 cm	500 cm - 600 cm
Without surrounding light	6 cm - 8 cm	> 600 cm

In the future, a more powerful photo detector, such as, photo-transistor can be used in replace of LDR to obtain higher data rates.

B. Self Adjust Detection Threshold

The current system is suitable for data transmission with a given surrounding light intensity. The receiver application regenerates binary data for the transmitter light pulses based on a threshold voltage. With change in surrounding light intensity, the threshold voltage changes. It is possible to adjust the threshold voltage by measuring surrounding light intensity over a period of time.

VII. Conclusion

In this project, data transmission using Li-Fi technology is successfully realized. It is also showed that, due to the intrinsic security nature of the Li-Fi transmission, it can be used for secure local area communications. By utilizing this characteristic, an intruder detection system is developed. The system can replace the existing Wi-Fi based communication to transmit sensor data from an IoT device to an IoT gateway using Li-Fi technology. When an obstacle (intruder) is detected on the transmission path, the system generates an alert to inform the user.

Appendix

A. Transmitter Code

```
#define TRANSMIT_LASER_PIN A3
#define SAMPLING_TIME 20

char* data = "\n\nThe device is safe. \n\nLi-Fi stands for Light-Fidelity. \nIt is a new
    technology and was proposed by the German physicist Harald Haas. \nLi-Fi provides
    transmission of data through light by varying the intentensity using an LED or Laser.";

// declaration of variables.
bool transmit_data = true;
int bytes_counter = 5;
int total_transmit_bytes;

void setup() {
  // initial setup.
  pinMode(TRANSMIT_LASER_PIN,OUTPUT);
  total_transmit_bytes = strlen(data);
}

void loop() {
  // transmit each bytes of the data.
  while(transmit_data) {
    transmit_byte(data[total_transmit_bytes - bytes_counter]);
    bytes_counter--;
    if(bytes_counter == 0) {
      transmit_data = false;
    }
  }

  transmit_data = true;
  bytes_counter = total_transmit_bytes;
  delay(1000);
}

// transmit a single byte.
void transmit_byte(char data_byte) {
  digitalWrite(TRANSMIT_LASER_PIN,LOW);
  delay(SAMPLING_TIME);

  for(int i = 0; i < 8; i++) {
    digitalWrite(TRANSMIT_LASER_PIN,(data_byte >> i) & 0x01);
    delay(SAMPLING_TIME);
  }

  digitalWrite(TRANSMIT_LASER_PIN,HIGH); // return to IDLE state after transmission
  delay(SAMPLING_TIME);
}
```

B. Receiver Code

```
#define LDR_PIN A5
#define LED_BUZZER_PIN 13
#define BUTTON_PIN 2
#define SAMPLING_TIME 20
#define LDR_THRESHOLD 300
#define DETECTION_THRESHOLD 200

// declaration of variables.
int detection_count = 0;
bool detected = false;
bool led_state = false;
bool previous_state = true;
bool current_state = true;
char buff[64];


void setup() {
  // initial setup.
  pinMode(LED_BUZZER_PIN,OUTPUT);
  pinMode(BUTTON_PIN, INPUT_PULLUP);
  Serial.begin(9600);

}

void loop() {
  // receive data until an intruder is detected.
  current_state = get_ldr();
  if (!detected) {
    if(!current_state && previous_state) {
      sprintf(buff, "%c", get_byte());
      Serial.print(buff);
    }

    if (!current_state) {
      detection_count = detection_count + 1;
    } else {
      detection_count = 0;
      detected = false;
    }
  }

  // check if an intruder is detected.
  if (detection_count > DETECTION_THRESHOLD) {
  detected = true;
  tone(LED_BUZZER_PIN, 440);
  Serial.print("\nDanger: Intrusion detected");
  delay(10);
  }

  // check if the button is pressed.
  if (!digitalRead(BUTTON_PIN)) {
  detected = false;
  noTone(LED_BUZZER_PIN);
  }

  previous_state = current_state;
}

// get ldr state.
bool get_ldr() {
  bool val = analogRead(LDR_PIN) > LDR_THRESHOLD ? true : false;
  return val;
}

// receive a single byte.
char get_byte() {
  char data_byte = 0;
```

```
  delay(SAMPLING_TIME * 1.5);
  for(int i = 0; i < 8; i++) {
    bool ldr_val = get_ldr();
    data_byte = data_byte | (char)ldr_val << i;
    delay(SAMPLING_TIME);
    if (!detected) {
      if (!ldr_val) {
        detection_count = detection_count + 1;
      } else {
        detection_count = 0;
        detected = false;
      }
    }
  }

  return data_byte;
}
```

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