Laser-Based Smart Communication System

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Abstract- This work presents the transmission of information in the form of light waves wirelessly in air. The aim of the Laser based Communication system is to enhance the communication capabilities for diverse applications by utilizing a high-speed data transmission technology and achieve faster and more efficient systems. The current highly used communication methods mainly depend on Radio Waves whose data transfer speed is slower when compared to light waves. As days pass there can be a shortage of availability of the radio waves spectrum due to more demand and usage. Another reason is that the laser beams are highly directional and focused narrow beams, hence less chances of interference. This system transmits the information which is encoded and modulated in the form of laser light using a laser diode in a free space wirelessly. Information can be an image or an audio file or a text. The transmitted laser signal is received by a photoreceiver, which is in Line of sight with the transmitter, in the receiver side and decoded to get the information. As light travels faster, this system achieves its speed. As a result of that, Latency is reduced. This has several advantages over traditional methods like higher bandwidth, high security, and resistance towards electromagnetic interferences. This can be used in many applications like satellite communication, underwater marine communication, in aerial vehicles and in high-speed data transmission areas.

Indexed Terms- Light Waves, spectrum, Laser Diode, Line of sight, Photo receiver.

I. INTRODUCTION

Laser based communication system is a free space wireless transmission system which uses light waves as its carrier wave, typically light in the form of a laser beam. First the data is encoded and modulated into a laser beam. The data can be a text or an audio file or an image. Then it is transmitted in free space to a receiver where it is detected and demodulated into the original signal.

1.1 BACKGROUND OF THE WORK

Light waves travel faster, have a wide highly available spectrum, beam can be narrowly focused, longer distance coverage and higher band width. This can be used where the traditional system is unable to sustain the needs of speed, distance coverage and interference to noises.

The current highly used communication method for data transfer is Wi-Fi, which depends on Radio Waves. These are highly insecure due to their range availability. Anybody can easily hack its access in this range, if they are in that range. Also, these radio waves are highly susceptible to interferences like electromagnetic waves. This may lead to more noises, attenuation, and loss of information. When considering speed, these are even slower than some traditional wired data transmission methods. The speed of Wi-Fi is 1-54 mbps whereas those traditional wired ones are almost 100mbps. Also, these RF using technologies suffer more due to congestion that is traffic due to large usage at the same time in that respective area and multi-user degradation.

As radio waves fail, there is a need to change it. Considering other waves, gamma rays ar3e hazardous, ultra violet rays are not good for skin, if exposed for a long duration. Similarly, infra-red rays are harmful to eyes in large quantities. So, the only choice is light waves. Light waves are not harmful, have higher speed of travel, higher bandwidth, are susceptible to electromagnetic waves, avoid congestions and cover large distances.

This light-based communication technology operates between 380nm and 780 nm in the wavelength range. This can be used for large distance communications like satellite communication. But as distance increases the cost for the components also increases.

1.2 MOTIVATION

The motivation for this laser-based communication system arises from the need for larger data transfer speed, higher security, higher bandwidth, reduced latency, reduced noise interference, system to be more effective, reliable, and cost efficient.

1.2.1 BANDWIDTH

Bandwidth refers to the capacity of the transmission system to transfer data. Higher bandwidth refers to transmitting at a faster rate. Laser based communication systems offer higher bandwidth than some traditional methods. This results in a large amount of data transfer in a small period.

1.2.2 SPEED

The speed of light is very high, that is 3X10^8 meters per second. Hence, using this light as a carrier wave for data transmission during modulation increases the speed of the transmission system. Optical communication can provide speed up to 100 Gbps.

1.2.3 SECURITY

Laser beams are highly directional and can be focused to a narrow beam. This makes it less susceptible to hacking. This light-based system also offers precise localization and user authentication, hence more secure.

1.2.4 RESISTANCE TO INFERENCE

This method of communication has a very least effect towards interference from other sources, such as radio frequency interference, electromagnetic interference which can degrade the signal quality and reduce the effectiveness of the communication system.

1.2.5 CONGESTION

The Bandwidth of light is much higher than radio waves, it is 1000 times more than that of radio waves. Hence, this system is congestion free and has resistance towards electromagnetic interference.

1.2.6 LATENCY

Latency is the delay between transmission and reception. Due to this system's high speed, hence has very less latency effect. The latency of a light-based communication system is three times less than WiFi.

1.2.7 LONG-DISTANCE COMMUNICATION

Laser-based communication can be used to transmit data over very long distances, such as satellite communications, between Earth and deep space probes, allowing for communication in situations where traditional methods would not be practical.

II. LITERATURE SURVEY

1. Rupali Dagade and Samadhan (2014), 'Laser Communication System' , International Journal of Electronics, Communication and Instrumentation Engineering Research and Development, vol.4, Issue 2, page 19- 24.

Laser communication is one of the key areas in wireless Communications. This paper includes analysis, optimization, design, and system-level development of signal transformation between satellites or any two sources. Which work similarly to fiber optic links, except the beam is transmitted through free space. While the transmitter and receiver must require line-of-sight conditions, they have the benefit of eliminating the need for broadcast rights and buried cables. Laser communications systems can be easily deployed since they are inexpensive, small, low power and do not require any radio interference studies.

2. Lawrance A J and Ohama G (2003), 'Exact calculation of bit error rates in communication Systems with chaotic modulation', IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, no.50, pp.1391-1400. The paper explores the calculation of exact bit error rates (BERs) for some single-user chaotic-shift-keying (CSK) communications systems, in contrast to approximate Gaussian Based approximations in current use. The conventional signal-to-noise-ratio approach is shown to give only lower bounds on the BERs. An analytical Gaussian approach based on exact mean and variance of the decoder function gives inexact results. Exact BERs are 6 given here for several CSK systems with spreading sequences from different types of chaotic maps. They achieve exactness by fully exploiting the dynamical and

statistical features of the systems and the results correspond theoretically to impractically large Monte Carlo simulations. A further aspect of the paper is the derivation of likelihood optimal bit decoders which can be superior to correlation decoders. The inapplicability of Gaussian assumptions is viewed through some exact distributional results for one system.

3. Wang J, Tao X and Zhang S, (2020), 'Free-space optical communication: A comprehensive review' , IEEE Communications Surveys and Tutorials, vol.22, no.4, pp.2597-2634.
This paper provides a comprehensive review of the state of the art in free-space optical communication. It covers the basics of optical communication, the challenges associated with free-space communication, and the current trends in research and development. The paper also discusses potential applications and future directions for the field.

4.Khoshnevis A, Uysal M and Alouini M S (2019), 'Atmospheric turbulence mitigation in free-space optical communication systems: A review', IEEE Transactions on Communications, vol.67, no.6, pp.4179- 4197.
This paper reviews recent advances in atmospheric turbulence mitigation techniques for free space optical communication systems. The paper covers topics such as adaptive optics, beam steering, and coding techniques, and discusses their effectiveness in mitigating the effects of atmospheric turbulence on communication performance.

5. Lesh J R, Robinson B S and Young D W (2018), 'Laser communication systems for deep space applications' , Proceedings of the IEEE, vol.106, no.3, pp.363-380. This paper provides a detailed review of laser communication systems for deep-space applications, such as interplanetary communication. The paper covers topics such as the design of deep-space laser communication systems, modulation techniques, and the challenges associated with deep-space communication.

III. OBJECTIVES AND METHODOLOGY

The methodology follows as first the data is encoded into a binary using python coding as laser diode can receive only ON and OFF signals which is done by generating a PWM wave. All these processes are done using a raspberry pi. Then the signal is given as an input to the laser diode. Based on the PWM signal the Laser diode on and off, this methodology is called on-off keying. The bits for indicating the start and end of the transmission are added. This is received by the photodiode at the receiver end. The receiver should be in line-of-sight with the transmitter and should be synchronized. After the photodiode receives the starting signal, at specific intervals, if light is detected 1 else 0. The received signal is decoded and converted into the data's original form.

3.1 OBJECTIVES

The main objective of the Laser based Communication system is to enhance the communication capabilities for diverse applications by utilizing a high-speed data transmission technology and achieve faster and more efficient systems. The objectives briefly depend on Reduce Latency error-less communication Faster transmission Long distant coverage Reliable and efficient system Latency is the delay between transmission and reception. If there is a large gap between time of transmission and reception, that is data takes more time to get received, latency is more. This may lead to data loss due to traffic in the network, addition of noises and may fail to detect the errors. Hence latency should be less. This can be achieved by increasing the speed of data transfer. If the distance between the transmitter is less, latency can be easily eliminated. Else speed plays the main role. As this system uses light as its carrier wave, by the benefit of light's traveling speed, the effect of latency is less here. When it comes to data transfer, one of the key points is it should be error free. There should be no data loss and noise should be effectively removed in the receiver end. To eliminate data loss, synchronization of transmitter and receiver, and intimation of start and stop of communication to the receiver is a must. Synchronization refers to alignment. Transmitter and receiver should be aligned properly. The speed of the transmission and reception should be the same. Otherwise, it may lead to data loss. If the transmitter is of higher speed than the receiver, data loss may happen as the receiver is slow to detect the signals. If the receiver is of high speed, there is a possibility of more noise. Also, this system uses light, and transmits the data in line-of-sight propagation, proper alignment of transmitter and receiver is must. For error correction forward error correction (FEC) protocol is used. It is done by adding redundant bits to the original data. These redundant bits are used by the receiver to correct the information without asking for retransmission of w=signal which may reduce the system's performance.

Every user needs a faster transmission of data. Speed is more important in crucial times. The speed of light is very high, that is 3X10^8 meters per second. Hence, using this light as a carrier wave during modulation at the transmitter end for data transmission increases the speed of the transmission system. Optical communication can provide speed up to 100 Gbps if used effectively. The data should be transferred effectively to large distances. Laser-based communication can be used to transmit data over very long distances, such as satellite communications, between Earth and deep space probes, allowing for communication in situations where traditional methods would not be practical. However, as distance increases the cost of components used may also increase to ensure more efficient and reliable communication without data loss.

When a communication system is error-free or has very less error, less interference to noise, has high data speed, higher bandwidth and can transmit through large distances it can be called as a reliable and efficient system for data transfer. Laser based communication system can achieve this by its ability of high speed , higher bandwidth and the algorithm used can reduce data loss.

3.2 PROCEDURAL FLOW

The procedure follows as first the data is encoded into a binary signal and generated as a PWM wave using raspberry pi. Then it is transmitted using a laser diode using on-off keying. This is received by the photodiode at the receiver end. The received signal is decoded and converted into the data's original form.

3.2.1 FLOW CHART

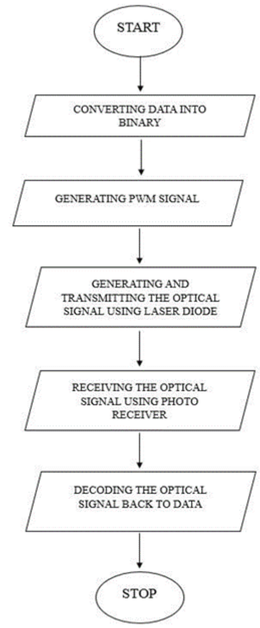

FIG 3.3 Main block Diagram

3.2.2 FLOW CHART EXPLANATION

1. CONVERTING DATA INTO BINARY

This method varies for each type of input. The data can be an image, text, audio file or video file. For images, First, store the image in a SD card with pre installed NOOBS OS. If not available download the NOOBS form. Next to process, the three channeled image is converted into a gray image that is a single channeled image. Then the intensity of each pixel is converted into a binary data. This binary data is transmitted along with its pixel width and height information. For audio files, First, store the audio file in a SD card with pre-installed NOOBS OS. If not available download the NOOBS form. Then the .wav file is read by the raspberry pi and is sampled using the required sampling frequency. Then, the sampled audio is digitized that is converted as binary and fed into the laser diode.For text, First, provide the text input. Then each characters along with space is converted into its respective ASCII value. Then the ASCII value is converted into its respective binary value for transmission.For videos it is tough for both decoding and transmission. We can either extract its audio alone and process as said above. Else can also extract the text form the speech in video and transmit it.

2. GENERATING PWM WAVE

The converted binary data contains only 0's and 1's. Pulse width modulation is a digital signal mainly used for representing or controlling ON and OFF. This wave contains only two peaks. High peek means 1 and flat peek means 0. Along with the binary data from the previous step, start and stop bits are also added. If forward error correction (FEC) protocol is enabled, redundant bits are also added. This was generated using raspberry pi. The final output of the raspberry pi is this PWM wave.

3. GENERATING AND TRANSMITTING THE OPTICAL SIGNAL USING PHOTO RECEIVER

The PWM wave from raspberry pi is given as the input to the laser diode. The laser diode is made ON and OFF based on this PWM signal. 1 means ON and 0 means OFF or vice versa can also be used.

4. RECEIVING THE OPTICAL SIGNAL USING PHOTO RECEIVER

The optical signal from the transmitter is received using the photo receiver. To achieve no data loss, synchronization of transmitter and receiver is must. Synchronization refers to alignment. Transmitter and receiver should be aligned properly. The speed of the transmission and reception should be the same.

Otherwise, it may lead to data loss. If the transmitter is of higher speed than the receiver, data loss may happen as the receiver is slow to detect the signals. If the receiver is of high speed, there is the possibility of more noise. Also, this system uses light, and the transmission of light is line- of-sight propagation, proper alignment of transmitter and receiver is must to receive properly.

2. DECODING THE OPTICAL SIGNAL BACK TO DATA

The signal is received as binary data. It should be decoded to get the original digital data that was originally modulated onto the laser beam. Image's incoming pixel values are saved in array form using the image's X and Y dimensions received. The output image is displayed using the built-in functions in embedded C code and is regenerated by using the image data in the received signal. The audio samples are similarly rebuilt, saved in an array format, and then plotted on the screen. The binary digits are simply translated into ASCII values and then back into the original text. The decoded digital data is then checked for errors using error correction techniques such as forward error correction (FEC). If errors are detected, they are corrected using appropriate techniques to ensure accurate data transmission

IV. METHODOLOGY OF THE PROPOSED WORK

WORKING OF TRANSMITTER

A laser-based communication system's transmitt side is made up of a variety of parts that wo together to modulate a laser beam with digital da and transmit it to a receiver through free space. transmitter, in general, transforms a signal into form that can be sent through a communicati channel.

1. DATA ENCODING

A proper coding technique is used to first encode the digital data which is going to be transferred. This could be a straightforward encoding method like binary coding or a sophisticated method like pulse position modulation (PPM). Encoding methodology varies for different types of input data. For pictures, place the image first on an SD card that has NOOBS OS already installed. Else

the images captured by the pi cam module can be used directly. The three channeled image is then processed by turning it into a single channeled gray image. Then each pixel's intensity is extracted and is transformed into a binary value. The pixel width and height of this binary data are also conveyed to the receiver. For audio files, Raspberry Pi reads the .wav file in SD card or the audio signal is applied to the 3.5 mm audio jack present on the Raspberry Pi board and samples it at the necessary sampling frequency. After being digitized and converted to binary, the sampled audio is then sent into the laser diode. For texts, First, enter text as input. Following that, then each character along with space is converted into its respective ASCII value. In order to transmit the ASCII value, it is then transformed into its corresponding binary value. It is challenging to decode and transmit videos. Its audio can be extracted separately and processed as stated above.

Else can also send the text that was extracted from the speech in a video. This text can be extracted using python coding. Also redundant bits are added to the data for error detection and correction at receiver end.All the above said process of encoding are done using Raspberry pi and python coding which is dumped into that processor.

2. MODULATION

The digital data is then modulated onto a laser beam and transmitted through empty space. In this system, first the binary data is converted into a PWM signal. It is done using Raspberry pi. Use the Python GPIO library, often either RPi.GPIO or gpiozero, to create a PWM (Pulse Width Modulation) wave on a Raspberry Pi. Set the GPIO pin up and import the required library. Give the binary input, then start generating the PWM signal. The PWM signal can also be modulated by altering the duty cycle. 'pwm_pin' and 'pwm_frequency' should be adjusted to match the unique hardware and needs.

3. AMPLIFICATION AND BEAM SHAPING

This PWM wave is given as input to the laser diode connected to the GPIO pin of the raspberry pi. The modified laser beam is then amplified to boost its power and make it acceptable for long- distance transmission. Amplification can be accomplished in several ways, including with the help of optical amplifiers or laser diodes. The enhanced laser beam is then tailored to guarantee precise receiver alignment. To accomplish this, guide the beam toward the receiver using lenses or mirrors.

4. TRANSMISSION

The laser beam is then transmitted through empty space toward the receiver after being modified and amplified. A line-of-sight transmission or an optical fiber may be used for this. Line-of-sight (LOS) propagation occurs when both transmitting and receiving antennas have an unrestricted direct line of sight between them. No major obstacles, such as hills, buildings, or other obstacles that might block or reflect the optical signals between the two sites during LOS propagation should be present.

- WORKING OF RECEIVER

A laser-based communication system's receiver side is made up of several parts that work together to detect and interpret the modulated laser beam with the objective to extract the digital data. The following steps make up the working process on the receiver side.

1. SIGNAL DETECTION

A photo detector initially captures the modulated laser beam without converting the optical signal back into a digital signal. To achieve this without any data loss and noises, their receiver should be in line-of-sight with the transmitter and synchronized with it. After receiving the start bit, the receiver starts to accept and store the data bits till the end bits are received.

2. AMPLIFICATION AND FILTERING

The digital signal is then amplified in order to boost it and prepare it for additional processing. Different methods, including transimpedance amplifiers or voltage amplifiers, can be used to amplify. After being amplified, the digital signal is filtered to remove any unwanted interference or noise that could have been included during transmission.

Multiple techniques, including low- pass or high-pass filtering, can be used to achieve filtering.

3. DEMODULATION

The filtered digital signal is then demodulated to retrieve the binary data that was originally modulated onto the laser beam. This is done using an Arduino uno microcontroller.

4. DECODING

The received binary data should be coded into its original form. The Arduino Uno board obtains a communications port at the receiver end for serial communication. After obtaining the X and Y dimensions of the image sent, the incoming pixel values for images are stored in array form. The embedded C code and built-in function colormap, imwrite are used to display the output image, which is created utilizing the image information included in the received signal. Similarly, the audio samples are reconstructed, stored in an array structure, subsequently plotted on the screen. For simplicity the binary digits are converted into ASCII values and then into original text. If required acknowledgement can be sent to secure correct communication.

V. RESULTS AND DISCUSSION

The information in this project is delivered and eceived through laser and is implemented in Raspberry pi and Arduino Nano. The design was mplemented and synthesized in RASPBERRY PI DE Software for raspberry pi with coding in python programming language and ARDUINO DE Software 2.0 for Arduino utilizing an Embedded C programming language.A laser- based communication system powered by an

Arduino and raspberry pi can be a fascinating project that exhibits the basics of light- based data ransmission. The RASPBERRY PI is used in this project to generate and modulate a laser beam that contains data encoded in its intensity and ARDUINO for receiving and decoding.

- RESULTS COMMUNICATION BETWEEN TRANSMITTER AND RECEIVER

The transfer of light signals between the ransmitter and receiver occurs in the laser- based communication system built using an Arduino Nano project. The transmitter turns digital data nto a modulated laser beam, which is then relayed o the receiver over free space. The modulated aser beam is then detected by the receiver using a photodiode and decoded back into the original digital data. The communication process can be divided into the following steps:

1. ENCODING DATA:

By altering the intensity of the laser beam using Pulse Width Modulation (PWM) techniques or other encoding methods such as Amplitude Shift Keying (ASK) or Frequency Shift Keying (FSK), the digital data to be conveyed is encoded into a modulated laser beam.

The modified laser beam is sent to the receiver through open space. The laser beam can be sent by air or fiber optic cable. The modulated laser beam is captured by the receiver using a photodiode, which converts the acquired optical signal into an electrical signal. To increase signal quality, the photodiode output signal is sent through an amplifier and filter circuit.

2. DATA DECODING:

Based on the encoding method employed at the transmitter end, the optical signal is subsequently decoded using appropriate decoding algorithms. After that, the decoded signal is transformed back into the original digital data.

3. FEEDBACK:

The receiver then processes the decoded data to offer feedback to the transmitter. For example, to signify that the data was properly received, the receiver may send a 30-acknowledgement signal back to the broadcaster if required to ensure proper communication.

- STRENGTHS AND LIMITATIONS

STRENGTHS

1. SPEED

An extremely high 3 X 10^8 meters per second is the speed of light. As a result, using this light during modulation as a carrier wave for data transfer speeds up the transmission system.

2. BANDWIDTH

The capability of a transmission system to carr data is referred to as bandwidth. Light has highe bandwidth. Faster transmission rates are associate with higher bandwidth. This causes a big amount o data to be transferred quickly.

3. LATENCY

The lag between transmission and reception is known as latency. The great speed of this technology means that it has relatively little latency impact. Light-based communication systems have a three times lower latency than WiFi..

4. LONG-DISTANCE COMMUNICATION

In instances where conventional methods would not be practicable, laser-based communication can be used to transfer data across extremely great distances, such as satellite communications, between Earth and deep space spacecraft.

5. CONGESTION

Light has a thousand times greater bandwidth than radio waves, which is a significant difference. As a result, this

system has resilience to electromagnetic interference and is uncongested.

- LIMITATIONS

Clear lines of sight between the transmitter and receiver are necessary for laser communication. The signal can be interfered with by obstacles like structures, trees, or atmospheric conditions, which reduces its range and dependability. Scintillation and beam wander are examples of atmospheric turbulence that can lead to variations in laser beam intensity. These factors can reduce signal quality and are especially evident at long distances. Despite the narrow beam and difficulties in intercepting laser communication, it can still be vulnerable to eavesdropping if not sufficiently secured. Compared to conventional radio-based systems, the deployment and maintenance of laser based communication systems can be more expensive and complex. It is necessary to use high-precision optics and alignment equipment, which can raise the overall cost. Laser communication is best suited for applications that are stationary or move slowly. It can be difficult to sustain high-speed mobility, such as communication with moving vehicles or aircraft.

- COST BENEFITS

When exceptionally high data rates, secure transmissions, or interference free communication are needed, optical communication, including laser-based point- to point networks, is frequently more affordable. Long-distance communication networks, satellite communication, and some industrial uses are a few examples.

Laser diode, raspberry pi, Arduino uno are less cost when compared to some traditional methods

The precise requirements of the application, financial limitations, and trade-offs between data rate, security, dependability, and environmental factors should be taken into consideration while deciding between optical communication and Wi-Fi. In some circumstances, a hybrid strategy may be employed, in which Wi-Fi offers wider connectivity but optical communication is used for some crucial links.

CONCLUSION & FUTURE WORKS

- CONCLUSION

Finally, laser-based communication is a system that employs modified laser beams to send data from one location to another. Its advantages over existing communication technologies include high bandwidth, low power consumption, and long- range capability. One of the most important advantages of laser-based communication is its security. The narrow beam of laser light makes it difficult for unauthorized individuals to intercept transmitted data. Laser communication is also immune to radio frequency interference, making it perfect for usage in areas with high levels of electromagnetic interference.

However, laser-based communication has several restrictions, such as the need for a clear line of sight between the transmitter and receiver, rendering it unsuitable for usage in inclement weather or in areas with barriers. Furthermore, laser based communication systems can be expensive and difficult to build.

\Despite these limitations, laser- based communication remains a potential technology for a variety of applications, including satellite communication, underwater communication, and inter-satellite communication. Ongoing research and development in this area is anticipated to lead to breakthroughs in laser- based communication technology, making it more accessible and economical for a variety of applications in the future.

- FUTURE WORK

Future work can be done by eliminating those limitations mentioned here. Can increase data

rate, reduce the cost of the system if distance is increased, making it even more immune to interference. The main is, improving its work if there are more obstacles in between the line of sight propagation.

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