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Laser Based Wireless Communication System for Secure Multimedia Transmission in Defense Operation

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Abstract: The project explores an innovative, short-range, point-to-point communication system utilizing laser light for secure, interference-free transmission of video, audio, and text signal. Existing wireless systems like Bluetooth and wi-fi face limitations such as congestion, interference, limited range, and security concerns in closed environments. RF communication, IR-based transmission, and wi-fi-based systems are commonly used but are susceptible to electromagnetic interference and lower data security and also only use Arduino & microcontroller. In existing system that only transmit audio and text. We propose a system where data is modulated on to a laser beam using a raspberry pi, transmitted through air, and then demodulated at the receiver using a photodiode sensor and another raspberry pi. A raspberry pi encodes and modulates multimedia data using python scripts in thonny platform, transmitting signals via a laser diode. A photodiode-based receiver demodulates the signals, allowing the data to be reconstructed and output as video, audio, text, or images. VLC protocols and simple error-checking methods are used to ensure reliable communication. Secure communication is essential in defence forces, underwater systems, and smart city applications. by using the laser communication "by utilizing advanced communication technologies, this project contributes to industry, innovation, and infrastructure development, aligning with global efforts in communication systems and engineering."
Keywords: Free Space Optics (FSO), Laser Communication, Raspberry Pi, Multimedia Transmission, Visible Light Communication (VLC), Defense Communication

1. INTRODUCTION

In the present era of advanced defense technologies, communication plays a vital role in ensuring the successful execution of military operations. The ability to transmit multimedia information such as live video, audio commands, and mission-critical data securely and without delay can often determine the outcome of defense missions. However, traditional wireless communication systems, primarily based on radio frequency (RF) or microwave transmission, face several limitations that restrict their effectiveness in modern warfare and high-security applications. Conventional RF-based communication channels are prone to electromagnetic interference, signal attenuation, and limited bandwidth, which directly affect the quality and reliability of data transmission. More critically, RF signals can be intercepted, jammed, or hacked by enemy forces, posing serious security threats to defense communications. These challenges have driven the need for an alternative communication system that offers higher security, better data rates, and immunity to interference while remaining compact and energy efficient. To address these limitations, laser-based wireless communication, also known as Free Space Optical (FSO) communication, has emerged as a promising solution. This technology enables line-of-sight data transmission using a highly focused laser beam, offering extremely high data transfer rates, minimal power loss, and resistance to electromagnetic interference. Unlike RF communication, laser communication does not require frequency licensing, making it both cost-effective and secure for short-range applications. In the proposed system, a Raspberry Pi is used as the core processing unit to modulate multimedia data such as video or audio onto a laser beam. The laser beam serves as the transmission medium, carrying the encoded data through free space to the receiver end. At the receiver, a photodiode sensor detects and demodulates the laser signal back into the original multimedia content. The system incorporates Python-based scripts, signal modulation/demodulation techniques, and tools such as VLC/OMX Player to enable real-time data processing and playback.

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This project aims to design and demonstrate a secure, efficient, and interference-free communication system capable of transmitting multimedia data over short distances. The implementation of such a system is especially valuable in defense operations, where reliability, confidentiality, and rapid data transmission are essential. By combining the strengths of optical communication and embedded technology, this project contributes to developing a next-generation communication model suitable for strategic military and secure field applications.

2. LITERATURE SURVEY

1. Implemented a low-cost, Raspberry Pi-powered laser communication link designed for secure data transfer between IoT nodes. The system achieved stable transmission up to 4 meters, supporting environmental sensing data and text transfer. Modulation techniques like PWM and On-Off Keying were analysed for efficiency and accuracy.
2. Focused on improving the performance of photodiode receivers in laser communication systems. It compared different signal amplification methods and receiver placement strategies. The findings helped improve bit error rates and signal clarity in Raspberry Pi-based VLC systems under ambient light interference.
3. A Raspberry Pi-based laser system was developed for encrypted communication in defense scenarios. It explored modulation encryption methods like FSK combined with AES encryption for secure video and voice data. The study highlighted VLC's resistance to jamming and its usefulness in line-of-sight tactical operations.
4. A prototype using laser-based VLC for transmitting multimedia data over short distances. A Raspberry Pi was used for digital signal processing and media encoding. It emphasized low latency and enhanced security due to the directional nature of laser beams. The study demonstrated 720p video streaming over 3 meters with minimal error rate under indoor lighting conditions.
5. This paper presents an overview of Visible Light Communication (VLC) systems using LEDs and lasers for wireless transmission. It discusses modulation techniques such as On-Off Keying (OOK) and Pulse Position Modulation (PPM). The study finds VLC suitable for secure, interference-free environments, making it ideal for indoor or military applications.
6. Implemented a low-cost laser-based system to transmit audio signals using an analog modulation technique. The receiver used a photodiode and amplifier circuit to reconstruct the original sound.
7. Used Raspberry Pi to transmit text data via laser. The system modulates ASCII characters and reconstructs them at the receiver using a photodiode connected to another Pi. It uses Python for signal processing.
8. Discussed the broader field of Free Space Optical (FSO) communication using lasers for long-distance, high-speed data transmission. It identifies limitations such as line-of-sight dependency and environmental sensitivity.
9. Studied uses Arduino boards for simple text data transmission using a laser. The system is effective for basic serial data but lacks multimedia support.
10. Offered a comprehensive survey on FSO communications in the context of 5G/Beyond-5G networks, covering enabling technologies (adaptive optics, modulation schemes), hybrid RF/FSO links, AI/ML techniques for link optimisation and identifies open challenges.
11. Reviewed hybrid FSO/RF networks aimed at achieving high-capacity backhaul for 5G; discusses architectures, trade-offs, and link switching strategies.
12. Focused on security issues in VLC systems at the physical layer (secrecy capacity, channel modelling, eavesdropping risk) and outlines future research on mobility, device orientation and combined VLC/RF systems.
13. Provided a review of FSO systems with a particular focus on outdoor links, atmospheric turbulence modelling, modulation scheme evaluations and system comparisons. Offers useful insight into modulation and channel issues (alignment, turbulence) for outdoor or uncontrolled environments — helping you identify constraints.
14. Presented experimental work combining structured random light beams with deep learning at the receiver to enhance resilience of FSO links in noisy/turbulent environments.
15. Focused on laser-powered UAV communications (where a laser charges the UAV and provides a data link), this study explores trajectory, power allocation, and link optimization under laser-energy constraints.

3. PROPOSED SYSTEM

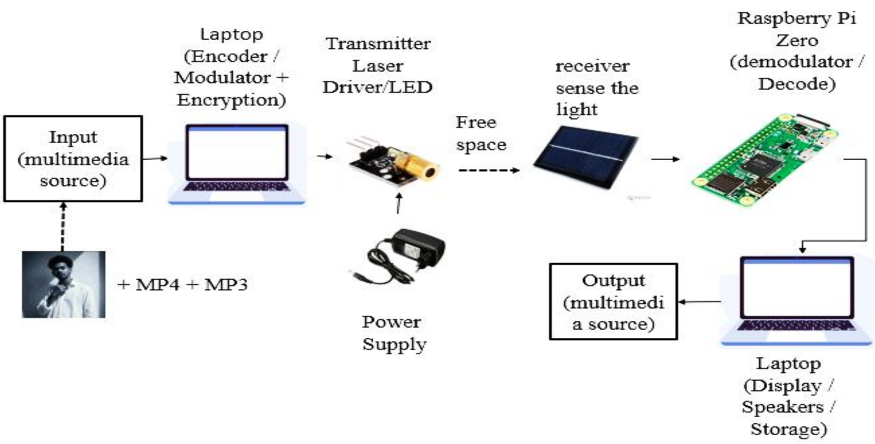

Figure 3.1. Block Diagram of Proposed System.

A Laser-Based Wireless Communication System designed for secure and high-speed multimedia transmission. Unlike conventional RF or IR systems, this setup uses visible or infrared laser light as the carrier for transmitting video, audio, or data signals between two points. The system leverages Raspberry Pi boards, Python-based control scripts, and optical communication components to achieve an efficient, low-cost, and secure data link.

3.1 Working Principle:

Transmitter Section: A Laptop acts as the multimedia source, providing video or audio content. The data is sent to the Raspberry Pi via a wired or wireless connection. The Raspberry Pi processes the data using Python scripts and performs signal encoding/modulation. The modulated signal is then applied to a Laser Diode, which converts the electrical signal into an optical signal (light beam).The laser beam carries the encoded data through free space toward the receiver.

Receiver Section: A Photodiode or Light Sensor detects the incoming laser beam and converts it back into an electrical signal. The output signal is then fed to another Raspberry Pi, which performs demodulation and decoding using Python programs. The recovered data is reconstructed into its original multimedia form (video/audio).

The decoded data is displayed or played back on a laptop or Monitor using VLC/OMX Player.

3.2 Key Features:

Secure Transmission: Laser communication provides a highly directional beam that is difficult to intercept or jam.

High Bandwidth: Supports the transfer of multimedia content such as live video and audio.

Error Checking: Utilizes basic error detection and correction algorithms to ensure data reliability.

Low Power Consumption: Requires minimal transmission power compared to RF systems.

Compact and Cost-Effective: Built using affordable components like Raspberry Pi, laser diodes, and photodiodes.

3.3. Transmitter: Laptop: Source of video or audio data.

Laser Diode: Converts electrical signals into a modulated laser beam for transmission.

3.4. Receiver: Photodiode Sensor: Detects the transmitted laser beam.

Raspberry Pi: Decodes and reconstructs the received optical data.

Laptop/Display: Outputs the recovered multimedia data using VLC/OMX player.

3.5. Advantages over Proposed System: Supports multimedia transmission (audio + video).Provides enhanced data security due to directional laser communication. Reduced interference immune to electromagnetic noise. Higher data rate compared to RF/IR systems. Enables error-free and real-time transmission for defense operations.

3.6. Hardware components:

1. Raspberry Pi Zero W
2. USB to Serial (TTL) Converter
3. Laser Diode Module
4. Photodiode / Laser Receiver Module
5. Small Solar Panel (or Photovoltaic Sensor)
6. Supporting Wires and Jumpers

4. SOFTWARE REQUIREMENTS

4.1 Operating System – Raspberry Pi OS (Raspbian)

The Raspberry Pi OS, formerly known as Raspbian, is a Debian-based Linux operating system optimized for the Raspberry Pi board. It provides a stable and lightweight platform to execute the project's Python scripts, manage GPIO pins, and perform multimedia operations.

Features: Built-in support for Python, OMX Player, and VLC Media Player. Efficient control of hardware interfaces (GPIO, I²C, SPI, UART).Compatible with remote login via SSH or VNC for easy programming and monitoring. Provides full access to Linux commands for system configuration and automation. Purpose in the Project: The Raspberry Pi OS acts as the core environment that handles both software execution and hardware communication for the transmitter and receiver units.

4.2. Programming Language – Python: Python is the main programming language used for system development. It offers extensive libraries for multimedia handling, hardware control, and communication protocols.

Functions Performed: Controls the laser diode (transmitter) and photodiode (receiver) using GPIO pins. Handles data encoding, signal modulation, and decoding at both ends. Executes error detection and correction algorithms to ensure reliable data transfer. Supports socket or serial communication for transferring multimedia data.

4.4. Multimedia Tools – VLC / OMX Player: Multimedia transmission requires real-time playback and encoding tools. In this project, both VLC and OMX Player are used depending on the environment.VLC Media Player: A cross-platform media player that supports almost all multimedia formats. It can also be controlled via command line or Python scripts to play video or audio files during transmission or reception.OMX Player: A lightweight media player optimized for Raspberry Pi's GPU. It provides smooth playback and minimal delay during multimedia streaming.

Purpose: To play the multimedia data (video/audio) at the transmitter. To receive and display the transmitted data at the receiver after decoding. Development Environment – Thonny IDET honny is a beginner-friendly Python Integrated Development Environment (IDE) pre-installed in Raspberry Pi OS. It is used for: Writing, testing, and debugging Python programs. Providing a clean interface for step-by-step code execution. Monitoring errors, variable states, and data flow in real time. To simplify the development and debugging process for Raspberry Pi-based projects without needing external software. Communication Protocols and Libraries to ensure efficient data transmission, the project utilizes basic networking and hardware libraries: Socket Programming: Used for communication between the laptop and Raspberry Pi or between two Raspberry Pi devices. It establishes a client-server model for data transfer.

Serial Communication (UART): Can be used for low-level control and data exchange between Raspberry Pi boards. RPi. GPIO Library: Provides access to control pins used for connecting the laser diode, photodiode, amplifiers, and other components.

Supporting Software: To assist with system management, monitoring, and file transfer, the following tools are used:

PuTTY: A terminal emulator used to remotely access Raspberry Pi over SSH. It allows the user to execute commands, monitor processes, and control the device from a computer.

WinSCP: A graphical interface tool for file transfer between the PC and Raspberry Pi. It is used to upload Python scripts, configuration files, or multimedia data.

5 HARDWARE REQUIREMENTS

The hardware components used in the Laser Based Wireless Communication System for Secure Multimedia Transmission are selected to ensure reliable, secure, and high-speed data transfer using free space optical communication. The system consists of a transmitter unit and a receiver unit, both controlled using Raspberry Pi boards.

1. Raspberry Pi Zero W

Quantity: 1 (Receiver)

The Raspberry Pi Zero W acts as the central processing unit of the system. It performs data demodulation, and decoding of multimedia data.

Figure5.1 Raspberry Pi

Features: 1 GHz single-core CPU, Built-in Wi-Fi and Bluetooth Supports Python, VLC, and OMX Player

Role in Project: Transmitter: Encodes and modulates multimedia data

Receiver: Decodes received optical signals and reconstructs data

2. Laser Diode Module

Quantity: 1 The laser diode module is used as the optical transmitter. It converts electrical signals from into a modulated laser beam.

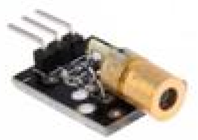

Figure 5.2. Laser Diode Module

Features: Narrow beam divergence, High directionality, Low power consumption

Role in Project: Transmits modulated multimedia data through free space

Provides secure, line-of-sight communication

3. Photodiode / Laser Receiver Module

Quantity: 1 The photodiode sensor detects the incoming laser beam and converts it into an electrical signal.

Figure 5.3. Photodiode

Features: High sensitivity to light, Fast response time, Low noise performance

Role in Project: Receives modulated laser signal, Converts optical signal to electrical signal for decoding

4. USB to Serial (TTL) Converter

Quantity: 1: The USB-to-TTL converter is used for serial communication between Raspberry Pi and external modules.

Figure 5.4.USB to Serial (TTL) Converter

Features: Supports UART communication, Plug-and-play USB interface

Role in Project: Enables data transfer and debugging, Used for communication testing

5. Photovoltaic Cell / Light Sensor (Optional)

Quantity: 1 A small solar panel or light sensor can be used to enhance signal detection.

Role in Project: Acts as an alternative optical receiver, Improves signal detection under low-light conditions

6. Power Supply : Quantity: 2 A stable power supply is required to operate the Raspberry Pi and optical components.

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Figure 5.5. Power Supply

Specifications: 5V DC, Minimum 2A current
Role in Project: Powers Raspberry Pi and laser module, Ensures stable operation

7. Connecting Wires and Jumper Cables

Used for connecting GPIO pins, sensors, and laser modules.
Role in Project: Provides electrical interconnections, Ensures flexible circuit configuration

8. Display Unit (Monitor / Laptop) : Quantity: 2Used to view transmitted and received multimedia data.

Figure 5.6. Laptop

Role in Project: Displays video, audio, and images, Used for testing and result analysis

Transmitter: The transmitter in this system is a laptop running a Python-based application designed using a graphical user interface (GUI) platform. The Python program acts as the main controller for sending multimedia data such as text, audio, images, and video. The interface allows the user to select the serial port, set the baud rate, choose the media file (like an image), and send it easily through the system.When the user selects a file (for example, an image) and clicks the "Send" button, the Python script reads the file and converts it into digital data (bytes). This data is then divided into small packets and transmitted through the serial port (COM3) as shown in the platform window. The program logs each step, such as START, payload size, and successful transmission, to confirm that the data is being sent correctly.The transmitted digital signal is passed to the laser driver circuit, which converts the binary data into light pulses. A logic '1' turns the laser ON and a logic '0' turns it OFF, creating an optical signal that carries the multimedia data through the free-space laser link. This Python-based transmitter platform makes the system user-friendly, flexible, and suitable for real-time multimedia transmission.

Receiver: The receiver section of the system is built using a Raspberry Pi connected to the photodiode receiver circuit and monitored through MobaXterm. MobaXterm is used as a remote display and serial monitoring tool to view the received data and control the Raspberry Pi interface in real time. When the laser signal reaches the receiver, the photodiode detects the optical pulses and converts them into electrical signals. These signals are then processed and decoded by the Raspberry Pi through a Python-based receiver program. The software interface shown in the receiver platform includes options such as port selection (/dev/ttyUSB0), baud rate setting (4800), and control buttons like Start Image, Start Audio, and Start Video.After the transmission begins, the Raspberry Pi reads the incoming serial data, identifies the START and STOP markers, and reconstructs the multimedia file (such as an image). The received file is automatically saved in the specified folder (e.g., /home/pi/Desktop/received/) and displayed in the preview window. The log section confirms successful reception by showing details like file size, identifier, and saved location.

6. RESULTS & DISCUSSION:

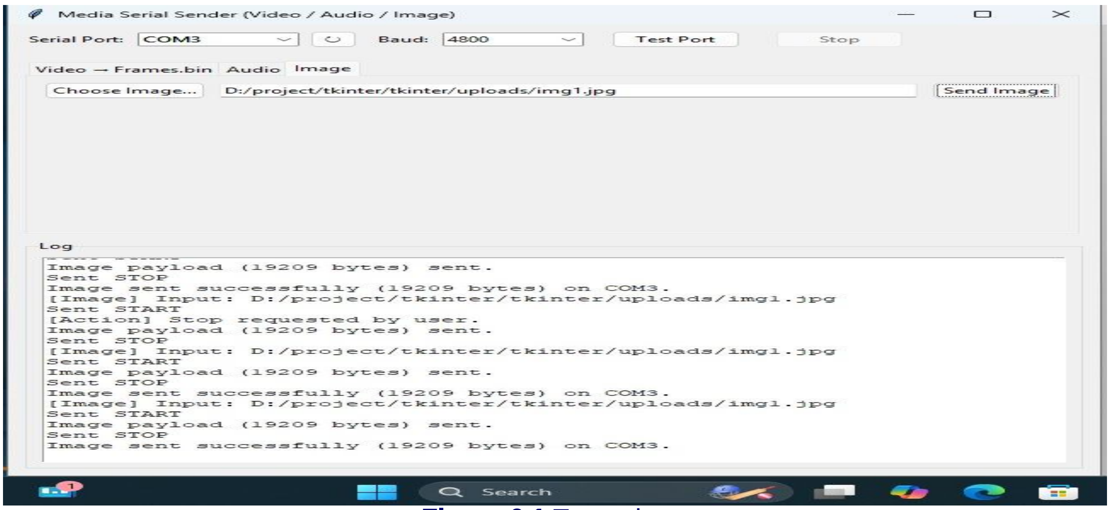

Figure 6.1 Transmitter

The hardware design of the laser-based wireless communication system is based on a laptop as the transmitter and a Raspberry Pi as the receiver. At the transmitter side, the laptop processes and encodes multimedia data such as text, audio, images, and video using Python software. The encoded digital data is then sent to the laser driver circuit, which controls the laser diode to transmit the data as optical signals through a line-of-sight link.

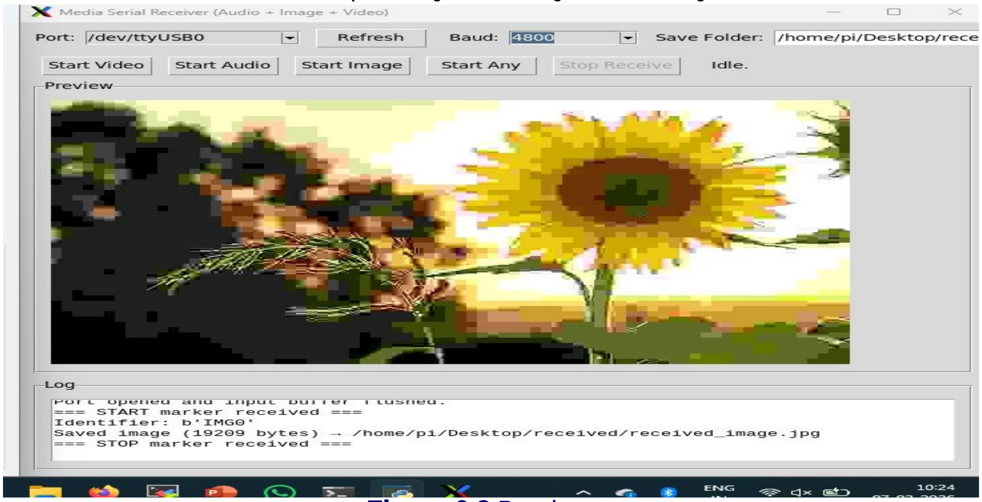

Figure 6.2 Receiver

At the receiver side, a photodiode along with an amplifier circuit detects the incoming laser beam and converts the optical signal into an electrical signal. This signal is fed to the Raspberry Pi, which performs decoding and data reconstruction. The received data is then displayed and monitored on the system using serial communication tools.

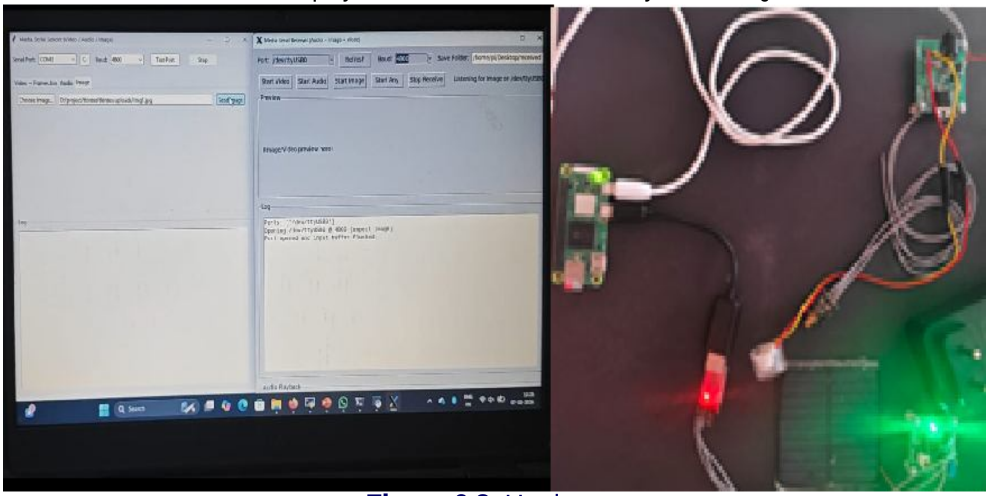

Figure 6.3. Hardware

Proper alignment of the laser diode and photodiode is essential for accurate signal reception and stable performance. Overall, the hardware setup is simple, low-power, and cost-effective, while providing secure, interference-free communication suitable for short-range multimedia transmission.

7. CONCLUSION

The Laser-Based Wireless Communication System for Secure Multimedia Transmission was successfully designed and implemented using a laptop as the transmitter and a Raspberry Pi as the receiver. The system demonstrated reliable transmission of text, audio, images, and short video data through a line-of-sight laser link. Python-based software and serial communication tools enabled smooth encoding, transmission, reception, and decoding of multimedia data. Overall, the project proves that laser-based communication is a cost-effective, secure, and practical solution for short-range high-security multimedia transmission.

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